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ABSTRACT

A study was undertaken to: (1) assess problems with UHF television systems; and (2) identify problem-solving activities on which different broadcast institutions could cooperate, The model for comparing UHF with VHF broadcast/reception services assigned performance disparity figures to each of the following elements: (1) transmitter and transmitting antenna; (2) propagation path; (3) receiving antenna; (4) receiving antenna transmission line; and (5) television receiver noise. This report describes the methodology for measuring each parameter, and it summarizes conclusions and recommendations. (EMH)

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# A QUANTITATIVE COMPARISON OF THE RELATIVE PERFORMANCE OF VHF AND UHF BROADCAST SYSTEMS

U S DEPARTMENT OF HEALTH, EDUCATION & WELFARE
NATIONAL INSTITUTE OF EDUCATION

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By

Philip A. Rubin
Director of Engineering Research
Corporation for Public Broadcasting
Washington, D. C.

W. J. Kessler and M. J. Wilhelm
W. J. Kessler Associates
Gainesville, Florida

June, 1974



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"FOR EVERY DIFFICULT AND COMPLEX PROBLEM,

THERE IS AN OBVIOUS SOLUTION THAT IS

SIMPLE, EASY - AND WRONG!"

H. L. Mencken

Copies of this document are for sale by the Corporation for Public Broadcasting, 888 16th Street, N.W., Washington, D.C. 20006 — Price $3.

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## SECTION 1

## INTRODUCTION

The preparation of this report was prompted by the belief in two premises. They are:

1. That the performance of the UHF TV broadcasting/reception system can be improved sufficiently to substantially narrow the performance gap currently existing between the VHF and UHF broadcasting systems; and,

2. That the most fruitful approach to the solution of any complex problem is first to identify the problem elements of the overall system and second, to assess the magnitude of the problem accurately.

Therefore, the objective of this report is not only to identify and assess the UHF system problem elements but to suggest areas of problem-solving activity in which all institutions representing the interests of the commercial and non-commercial TV broadcast industry may cooperate. Such institutions would include, but not be limited to:

1. The TV broadcast equipment and receiver manufacturing industry,

2. The Federal Communications Commission,

3. The Congress of the United States,

4. The All-Channel Television Society,

5. The National Electronics Service Dealers Association, and

6. Last, but not least, organizations such as the CPB, PBS, NAEB, NAB, EIA, and AMST.

The general approach to the VHF-UHF problem treated in this report is to provide an accurate objective comparison of the major elements of the VHF-UHF TV broadcast/reception system by assigning performance-disparity figures to each element so that a total system comparison can be established. The basic elements of the VHF-UHF broadcast/reception system to be considered in this report are summarized in the block diagram shown in Figure 1.

The signal strength in microvolts per meter available at a standard elevation of 30' above ground level at a potential receiving location is a necessary but insufficient condition for satisfactory system performance. After all, it is the picture quality displayed on the screen of a television receiver, rather than the available signal strength that is the important factor. At least one important characteristic of a satisfactory picture displayed on the screen of a television receiver is a "picture-to-snow" ratio which in turn is a linear function of the carrier-to-noise ration (C/N) available at the TV receiver front end.

Accordingly, comparisons of the performance of the total VHF-UHF system in this report will be based on the final carrier-to-noise (C/N) ratio difference ($\Delta$C/N) available at the input stage of a typical television receiver. A symbolic statement of the procedure employed to establish the difference in C/N for VHF and UHF systems can be expressed as follows:

$$\Delta C/N = \Delta dB(T) + \Delta dB(P) + \Delta dB(A) + \Delta dB(L) + \Delta dB(NF)$$

Where all the terms represent the differences in dB between the VHF and UHF systems being compared: T the transmitter plant, P the propagation path, A the receiving antenna, L the antenna-receiver transmission line, and NF the noise figure of the TV tuner.

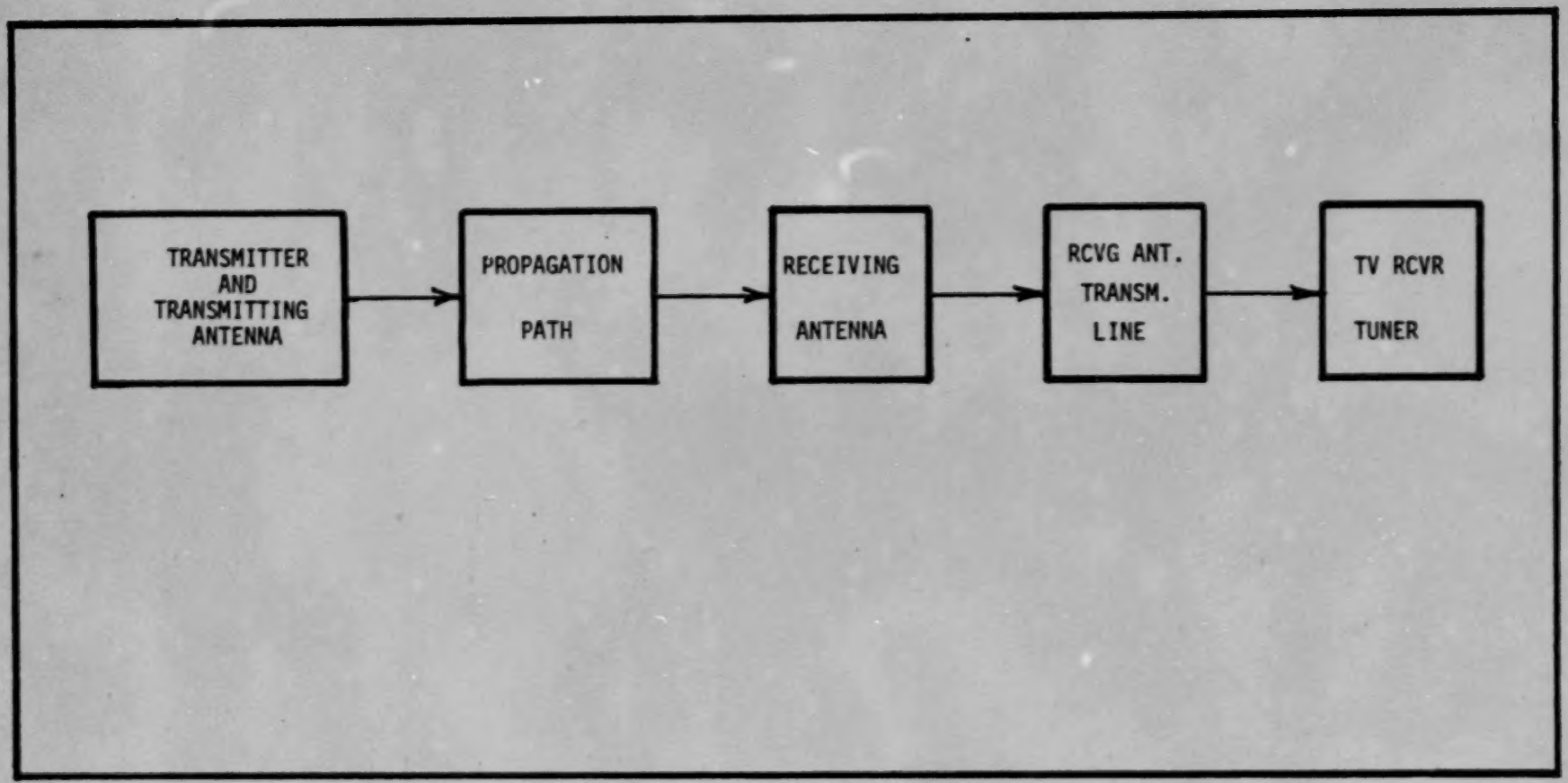


FIGURE 1: ELEMENTS OF THE TELEVISION TRANSMISSION/RECEPTION SYSTEM.

## SECTION 2

## THE TRANSMITTER/TRANSMITTING ANTENNA SUBSYSTEM

There are several essential differences between the transmitting plants of UHF and VHF stations, aside from the obvious differences in operating frequencies of the transmitters. The most significant difference is that the operation of VHF stations at the regulatory maximum effective radiated power (100 kw for Channels 2-6 and 316 kw for Channels 7-13) is the rule, while operation of UHF stations at the regulatory maximum effective radiated power (5 megawatts) is the exception, and a rather rare one at that.

There appears to be a clear need for UHF stations to utilize higher effective radiated powers to narrow the performance gap between VHF and UHF. In this section, a comparison of the components of UHF and VHF transmitting plants shows that high power UHF operation, while beset with some technical complexities, is not precluded by technical considerations, but is severely affected by economic factors.

### Transmitter

VHF transmitters are available in a range of power outputs and configurations, the most common varieties being transmitters with power outputs ranging from 5 kw to 50 kw peak visual. UHF transmitters, while available in various power output levels ranging, most commonly from 30 kw to 220 kw, are made up of 2 basic "building blocks", the 30 kw and the 55 kw klystron final amplifier. The 30 kw amplifier is used principally for transmitters with 30 kw and 60 kw power outputs, while the 55 kw amplifier finds application in transmitters from 55 kw to 220 kw, conventionally in even multiples of 55 kw. Thus, there are available today the basic 55 kw transmitter using a single 55 kw visual final amplifier, a 110 kw transmitter using two 55 kw visual final amplifiers, and a 220 kw transmitter using four 55 kw amplifiers.* To date, the 220 kw

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* Although not commonly used, a 165 kw transmitter using three 55 kw final amplifiers is also available.

transmitter is the largest manufactured although there are no technical constraints on the development of more powerful transmitters using the basic 55 kw amplifier "building block". For example, a 550 kw transmitter using ten 55 kw visual final amplifiers, would be technically feasible.

The high power UHF transmitters described above have been made possible by the development of the high-power, high gain, multiple cavity klystron amplifier. Were it not for the development of these tubes, the UHF transmitter would have to rely on conventional tetrodes similar to those used in VHF transmitters, and it is doubtful whether today's high power UHF transmitters would be technically or economically feasible, particularly on the high UHF channels, because of the tetrode's relatively low gain, limited power output, and relatively short life, at UHF frequencies.

The significant advantages of the multiple-cavity klystron at UHF are its high power output, high gain, and large bandwidth as typified by the following characteristics of the Varian 953 A/B, 954 A/B, 955 A/B series of tube, the five-cavity klystron used in most 55 kw amplifiers:

| | |
|---|---|
| Power Output: | Up to 58 kw |
| Gain: | 47 dB |
| Bandwidth: | 8 mHz at the 1 dB points |

The high gain of the klystron minimizes the number of RF stages required in the transmitter, the wide bandwidth characteristic does away with the need for tedious and critical "broad banding" adjustments, and the tube has exhibited stability, reliability, and long life. However, the typical UHF transmitter's overall efficiency in terms of primary power consumption vs RF power output is relatively low, compared to the typical VHF transmitter.

For the UHF broadcaster, the relatively low efficiency of the UHF transmitter presents a dual problem from the standpoint of power consumption. First, the UHF broadcaster generally must utilize a higher power transmitter than his VHF counterpart, and the use of the higher power transmitter results in

greater power consumption. Secondly, the UHF transmitter is less efficient (AC power consumed vs RF power output) than a VHF transmitter, resulting in a greater power consumption per kilowatt output.

The quantitative aspects of UHF vs VHF transmitter power consumption are shown in Figures 2 and 3. Figure 2 shows primary power consumption as a function of RF power output (peak visual) for the range of commonly available VHF and UHF transmitters. The power consumption figures shown are for the entire transmitter, including the exciter, IPA, aural and visual final amplifiers, blower motors, etc., and are based on an aural power output equal to 20% of the peak visual power. Figure 3 translates the power consumption information in Figure 2 into the per-month cost of primary power.

There is a considerable variation in electrical power rates throughout the United States. Therefore, the actual cost of operation of a given transmitter will be dependent on its locale. The costs shown in Figure 3 are based on those prevailing in the Southeastern United States, and are computed on the basis of an 18-hour, 7-day per week broadcast schedule. However, regardless of the power rates in effect for a given station or the length of the broadcast day, the ratio of UHF costs vs VHF costs and the ratio of costs among the various sizes of UHF transmitters shown in Figure 3 will remain essentially constant.

The power cost in Figure 3 does not increase in direct Proportion to the power consumption figures shown in Figure 2 because of incorporation of the "large user" discounts available from power companies. However, with the increasingly urgent shortage of energy and a rising public sentiment against the small residential power user having to subsidize the larger user who gets power at a "bargain" rate, the shape of the curves in Figure 3 may well be inverted by future changes in marketing policy. Therefore, the large user may find himself paying more per KWH for the privilege of using large amounts of a scarce commodity. Even if the "large user" rates continue in force, the current world situation and the consequent shortage of fuel, particularly low-sulphur content oil, for use in power generating plants, point to a significant increase in the cost of electrical power for all users large and small.

As would be expected, the capital cost of television transmitters is also significantly greater for UHF transmitters than for VHF transmitters, particularly for the case in which both the VHF and UHF stations are operating at their regulatory maximum effective radiated power. Figure 4 shows capital cost as a function of transmitter power output for UHF transmitters, high-band VHF transmitters and low-band VHF transmitters.

Hope has been expressed that a lower cost, higher power, more efficient UHF transmitter can be developed which will permit more economical UHF facilities, and that new sources of electrical power will be found which will alleviate the energy shortage and result in lower electrical power costs. There is no doubt that continued research into refinement of existing power amplifying devices, notably the klystron, could result in an improvement in efficiency. However, this improvement, desirable as it may be, is not likely to provide significant relief in the immediate future of the capital or operating cost burden imposed on the UHF broadcaster relative to his VHF counterpart. Even if the efficiency and capital cost of UHF transmitters were made equal to those of VHF, which is unlikely, the fact remains that the UHF broadcaster must employ a higher power transmitter to even approach parity of coverage with a VHF station, and this fact alone indicates that the UHF broadcaster will remain behind the economic eight-ball for the foreseeable future. Similar considerations pertain with respect to the availability of cheap and abundant electrical power. While this is a goal devoutly to be wished, technology, the reserves of fossil fuel, and the current world crisis involving the major oil producing countries, all indicate that things will get a lot worse before they get better, and that even maintenance of the status quo with regard to power availability and cost would be a major achievement.

Transmitting Antennas

The gain of currently available VHF transmitting antennas varies from a power gain ratio of one to a power gain ratio of 18 (0 dB to 12.55 dB) for the commonly available omnidirectional transmitting antennas. The gain of currently available UHF transmitting antennas varies from a power gain ratio of 6 to a power gain ratio of 50 (7.78 dB to 17 dB) for the commonly available omnidirectional transmitting antennas. It is the consensus of antenna engineers,

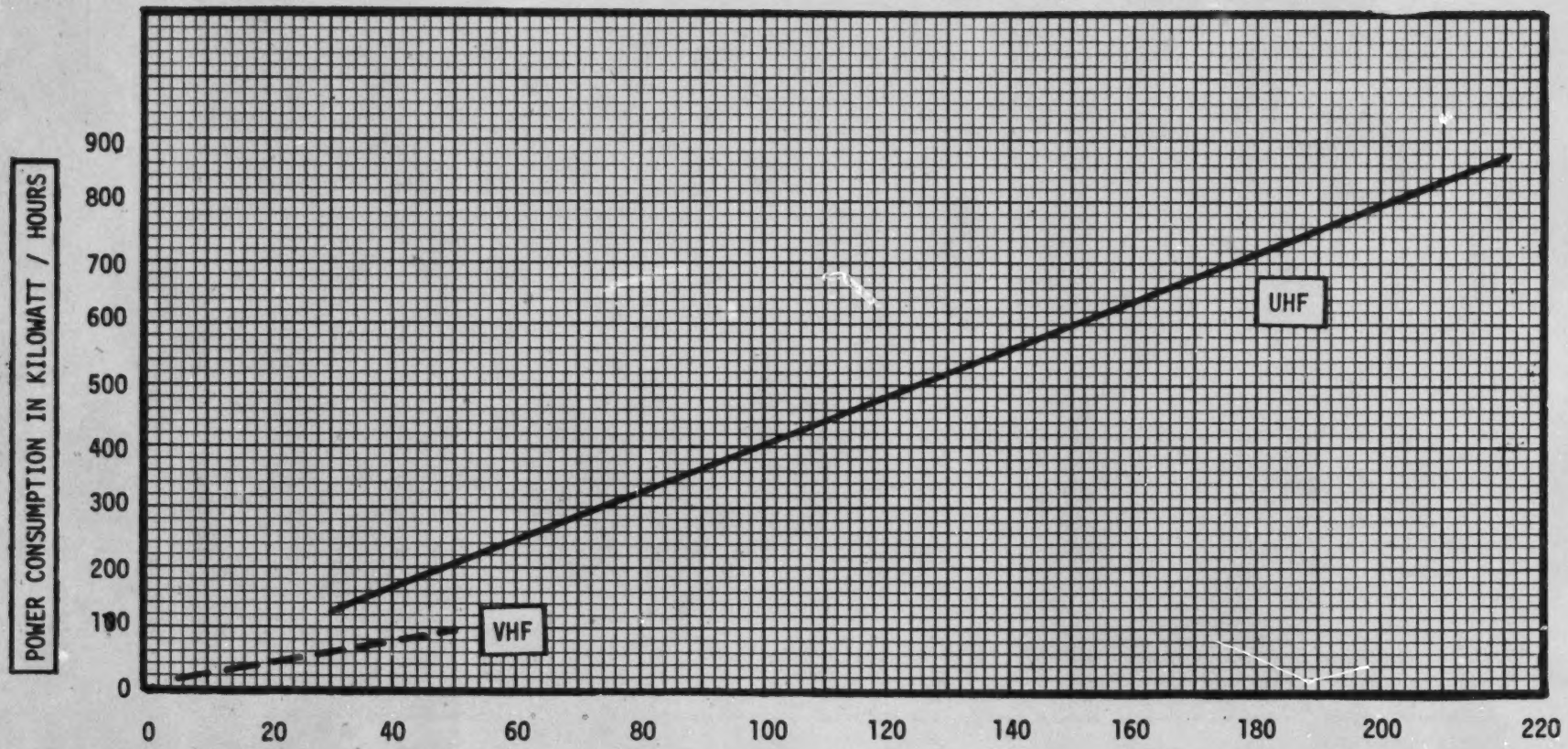


FIGURE 2: PRIMARY POWER CONSUMPTION OF AVAILABLE UHF & VHF TRANSMITTERS AS A FUNCTION OF POWER OUTPUT

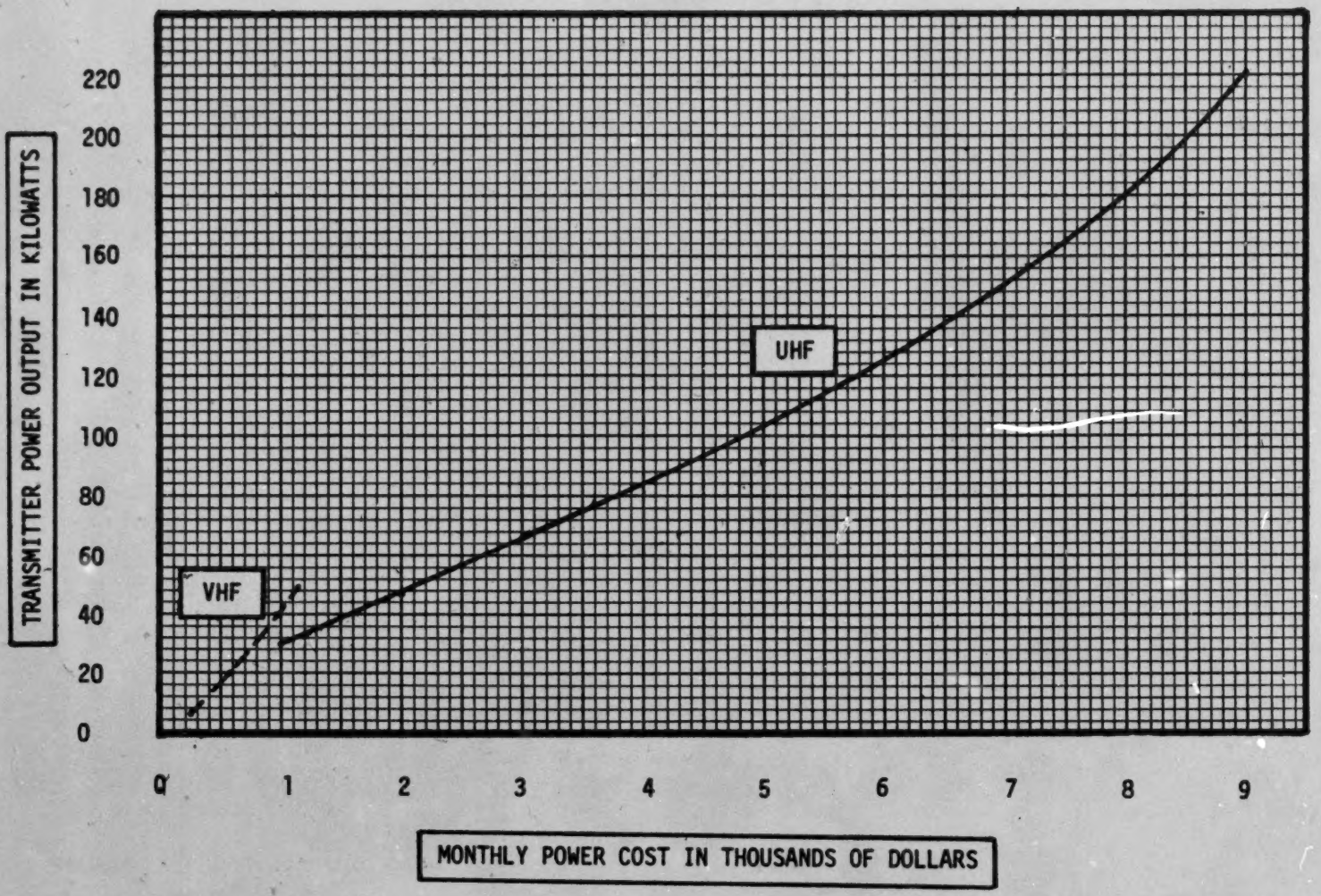


FIGURE 3: POWER OUTPUT OF AVAILABLE VHF & UHF TRANSMITTERS AS A FUNCTION OF PRIMARY POWER COST

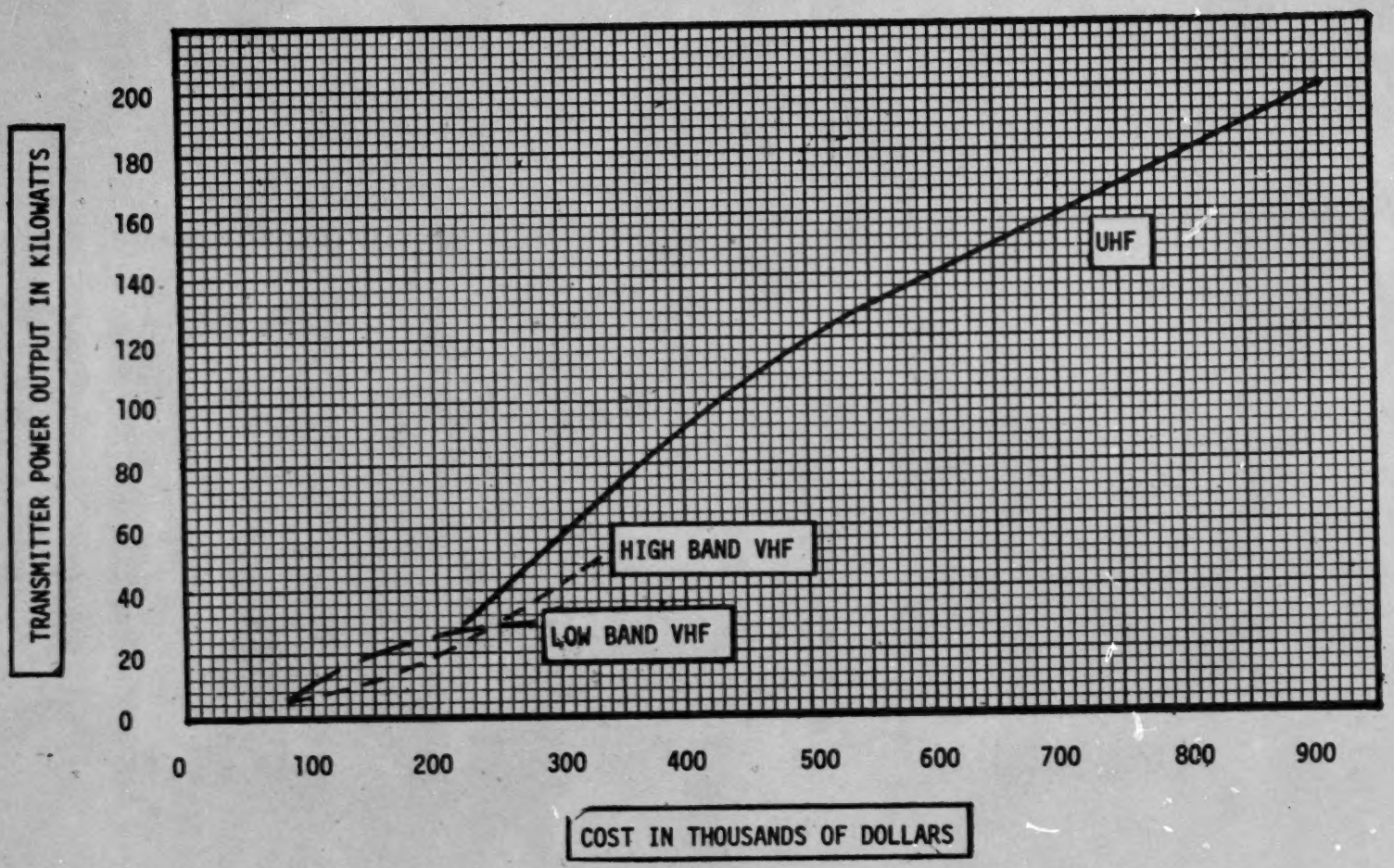


FIGURE 4: UHF & VHF TRANSMITTER POWER OUTPUT AS A FUNCTION OF CAPITAL COST

surveyed informally in October of 1973, that, except in special cases, a power gain ratio of 50 represents the practical upper limit on UHF transmitting antenna gain. The reasons behind this upper limit are a complex combination of factors associated with phase changes along extremely long antenna apertures, mechanical rigidity constraints, and most importantly, the "close-in coverage" problems associated with the extremely narrow vertical beamwidths which are a necessary consequence of the use of high-gain antennas.

A power ratio of 50 does not represent the absolute maximum limit on attainable antenna gain from a technical standpoint. Power gains of 60 or 70 (17.78 dB and 18.45 dB) might be achieved. However, of the engineers contacted who are responsible for antenna design at the major antenna manufacturers, none would commit themselves to estimating the cost of antennas with gains substantially in excess of 50, nor would they speculate as to whether antennas with gains in excess of 50 would perform satisfactorily in a practical installation.

With respect to higher-gain VHF antennas, the limitations appear to be primarily economic, up to the same gain limit of 50. VHF antennas are physically large structures compared to UHF, and above a limit of approximately a times 18 power gain (12.55 dB), it becomes more economical to achieve a given ERP with increased transmitter power rather than with larger antennas.

The economic aspects of high gain UHF antennas are twofold. First, is the fundamental physical fact that each 3 dB increase in antenna gain results in a doubling of the power-gain ratio and hence an approximate doubling of the length of the antenna. Thus the structural considerations associated with each 3 dB increase in gain results in more than a doubling of the antenna cost as shown in Figure 5. Second, the use of physically large, high-gain transmitting antennas imposes a higher windloading on the supporting tower than do smaller, lower-gain antennas. Additionally, tower sway characteristics become more important with high-gain antennas characterized by narrow vertical beamwidths, since excessive sway under moderate or high-wind conditions can "tilt" the antenna beam above or below the radio horizon where it is normally aimed. Consequently, compared with smaller antennas, a high-gain antenna requires a

stronger tower to support the additional weight and to accommodate the higher overturning moment of the antenna, and a more rigid tower to restrain antenna sway. These two considerations add up to increased tower cost, and unfortunately, the cost of steel, guy cable, and consequently towers, is rising rapidly in step, or possibly more rapidly, than the general level of prices in the economy.

Transmission Line

The choice of transmission line for VHF stations does not pose much of a problem. 3 1/8" diameter rigid coaxial line is conventionally used for low-band VHF facilities, will accommodate transmitter powers in excess of 50 kw, and offers fairly low attenuation (nominally 0.09 dB per 100' at Channel 6). 3 1/8" line is also used for many high-band television facilities, although 6 1/8" line is also common for reasons of reduced attenuation and/or higher power-handling capacity, particularly for high-channel stations utilizing single-line feeds to their antennas.

6 1/8" line is also a common choice for UHF stations with moderate transmitter powers of 30 kw, 55 kw, and 60 kw. However, line loss is significantly higher at UHF than at VHF for 6 1/8" line. Line loss at Channel 14 is nominally 0.105 dB per 100', rising to 0.1415 per 100 at Channel 69. A real technical conundrum exists with respect to the choice of transmission line for UHF stations utilizing high power (110 kw and up) transmitters. The use of high power transmitters dictates the use of large-diameter transmission line with high power-handling capacity, but perversely, as line diameter increases, limitations are imposed on the maximum frequency which the line will accommodate without excessive attenuation. That is, there exists a "cutoff frequency" at which the signal in the line ceases to propagate in the relatively low-loss $TE_{11}$ mode. The cutoff frequency of 3 1/8" and 6 1/8" line is well above the upper frequency of the UHF band. However, for 8 3/16" line, the cutoff frequency falls at Channel 47, and for 9 3/16" line, the cutoff frequency falls at Channel 40. Either 8 3/16" or 9 3/16" line suffices, on low channels, for use with 110 kw transmitters. However, 220 kw transmitters impose severe demands on the power handling capability of even the 9 3/16" line.

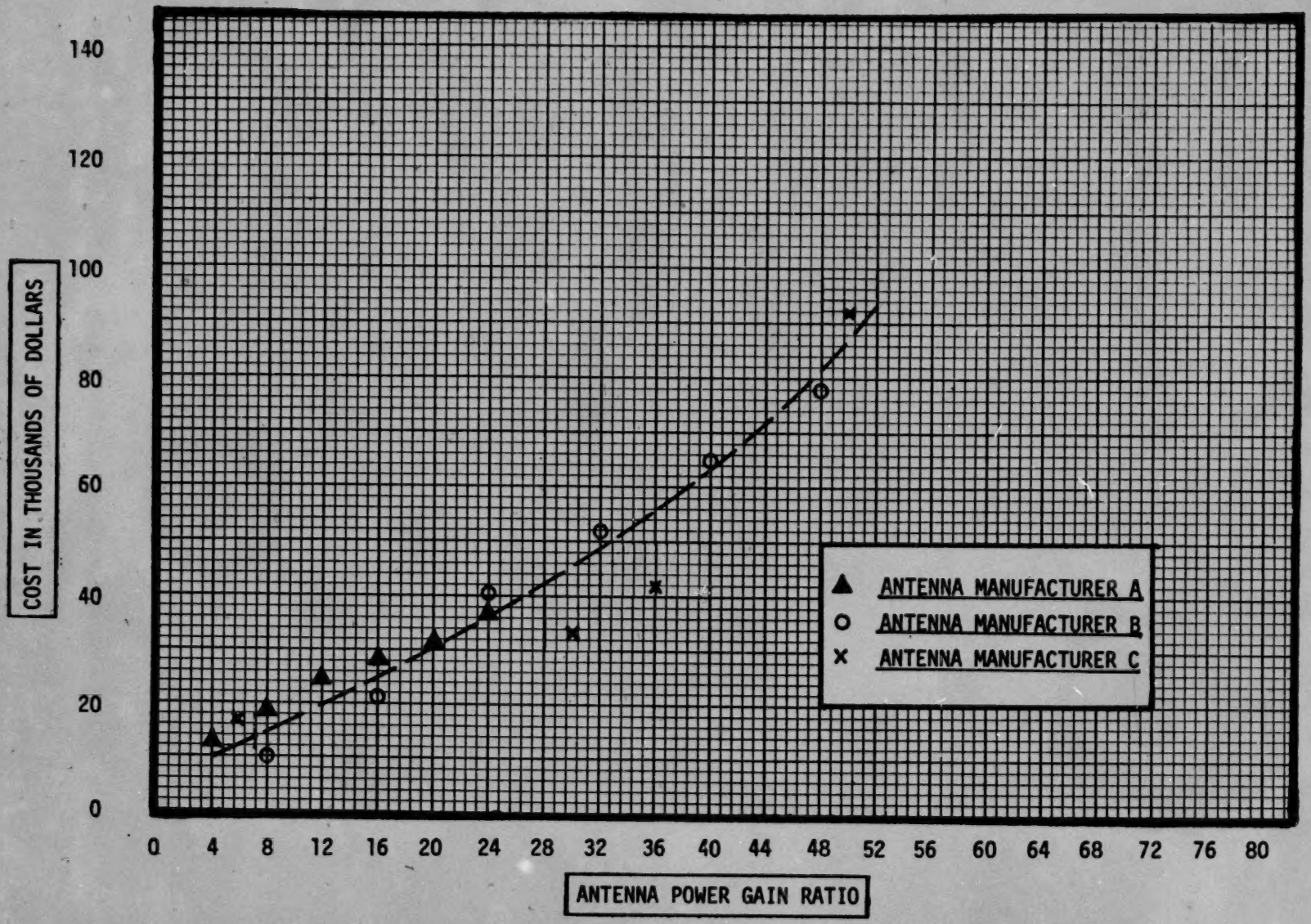


FIGURE 5: UHF TRANSMITTING ANTENNA COSTS AS A FUNCTION OF POWER GAIN RATIO

In order to utilize 9 3/16" line with 220 kw transmitters, it is necessary to employ gaseous dielectrics with heat transfer coefficients greater than the conventionally used nitrogen dielectric. The 220 kw transmitter at WDCA in Washington, D. C. employs 9 3/16" line with Freon as a dielectric and, to date at least, the 9 3/16" line is proving adequate to the task. However, on high channels (40 and above) or with higher transmitter powers, the UHF broadcaster must rely on rectangular waveguide in place of transmission line. The rectangular waveguide, typically BWG-1400 or BWG-1500, offers high-power handling capability, 625 kw for BWG-1400 and 750 kw for BWG-1500, and low attenuation, 0.0787 dB/100' for BWG-1400 and 0.0678 dB/100' for BWG-1500, at Channel 42, the middle of the UHF band. However, cost factors again operate to the detriment of the UHF broadcaster. Waveguide is not only more costly than coaxial transmission line, but its large cross-section imposes greater windloading on the tower than does coaxial line, thus requiring a stronger and consequently, more expensive tower structure.

Towers

The height of the supporting structure for a UHF antenna naturally has a direct influence on the coverage of either VHF or UHF stations. VHF stations may employ antenna heights of up to 1000' above average terrain in FCC "Zone 1" and up to 2000' above average terrain in "Zones 2 and 3".[1] Above these heights, VHF stations are required to reduce ERP as a function of the amount of height increase in excess of the above maxima. UHF stations are permitted to operate with maximum ERP of 5 megawatts in any zone, but must reduce ERP when operating at heights in excess of 2000' above average terrain. With these regulations in mind, it would seem that UHF stations could reduce coverage disparity relative to VHF stations by employing higher towers. However, there are two practical limitations restricting the maximum height of towers. The first is the matter of airspace clearance. There are few areas in the United States where towers in excess of 1000 feet above ground level may be located without constituting an aeronautical hazard. If a high tower is determined to be a hazard to aircraft by the FAA, the FCC will not issue a Construction Permit for the facility. The second practical limitation is again, the matter of cost. Figure 6 shows cost as a function of tower height for "typical" (i.e., EIA Zone A - standard soil conditions) towers of various heights. The rapid rise in cost for towers in excess of 1000 feet indicates that towers of over 1000' must be reserved only for the most affluent

of UHF operators, and necessarily only those affluent operators located in an area where aircraft traffic would not be interfered with by a high tower, a rare set of circumstances indeed.

Summary of Cost Factors

The cost factor may be most readily summarized by examination of the combined capital and operating costs of maximum-power VHF facilities and various power-level UHF facilities over a period of time. The results of such an examination are shown in Figures 7 and 8. A period of ten years has been chosen to present these combined capital-operating costs.

Figures 7 and 8 show the cumulative costs of implementing various transmitting facilities and operating them for a 10-year period. The initial capital costs are based on the expenses incurred in obtaining a complete transmitting plant, transmitter, antenna, tower, transmission line, input and monitoring equipment, building, and all accessories. The operating costs are based on power consumption and maintenance and replacement components expense. The total maintenance expenses are estimated at 7.5% per year of the capital cost of the transmitter and other active electronic equipment. Figure 7 shows the comparative cumulative capital and operating cost of "full power" Low-Band VHF, High-Band VHF, and UHF facilities, all with 1000' towers. Figure 8 shows the cumulative capital and operating costs for UHF facilities ranging from an ERP of 500 kilowatts to 5 megawatts. Figures 7 and 8 do not include allowances for depreciation of equipment, nor do they attempt to include the probable increase in electrical power cost which may occur because of the energy crisis.

The cost data presented in the foregoing sections casts into sharp relief the fact that substantial funding would be required to permit most existing and future UHF stations to operate at the maximum regulatory ERP of five megawatts. Furthermore, as will be shown in a later section it is not possible to reduce the UHF-VHF performance gap by increases in UHF power and antenna height alone. Those who would advocate equalizing the VHF-UHF performance difference by raising the present 5 megawatt ERP limit imposed by the FCC may mentally extrapolate the cost data shown to whatever ERP level they wish. However, it would appear from the data presented, and from a knowledge of the economic status of most Public stations, that a 5 megawatt facility represents a practical maximum for UHF stations unless unprecedented overall transmitter efficiency breakthroughs can be achieved.

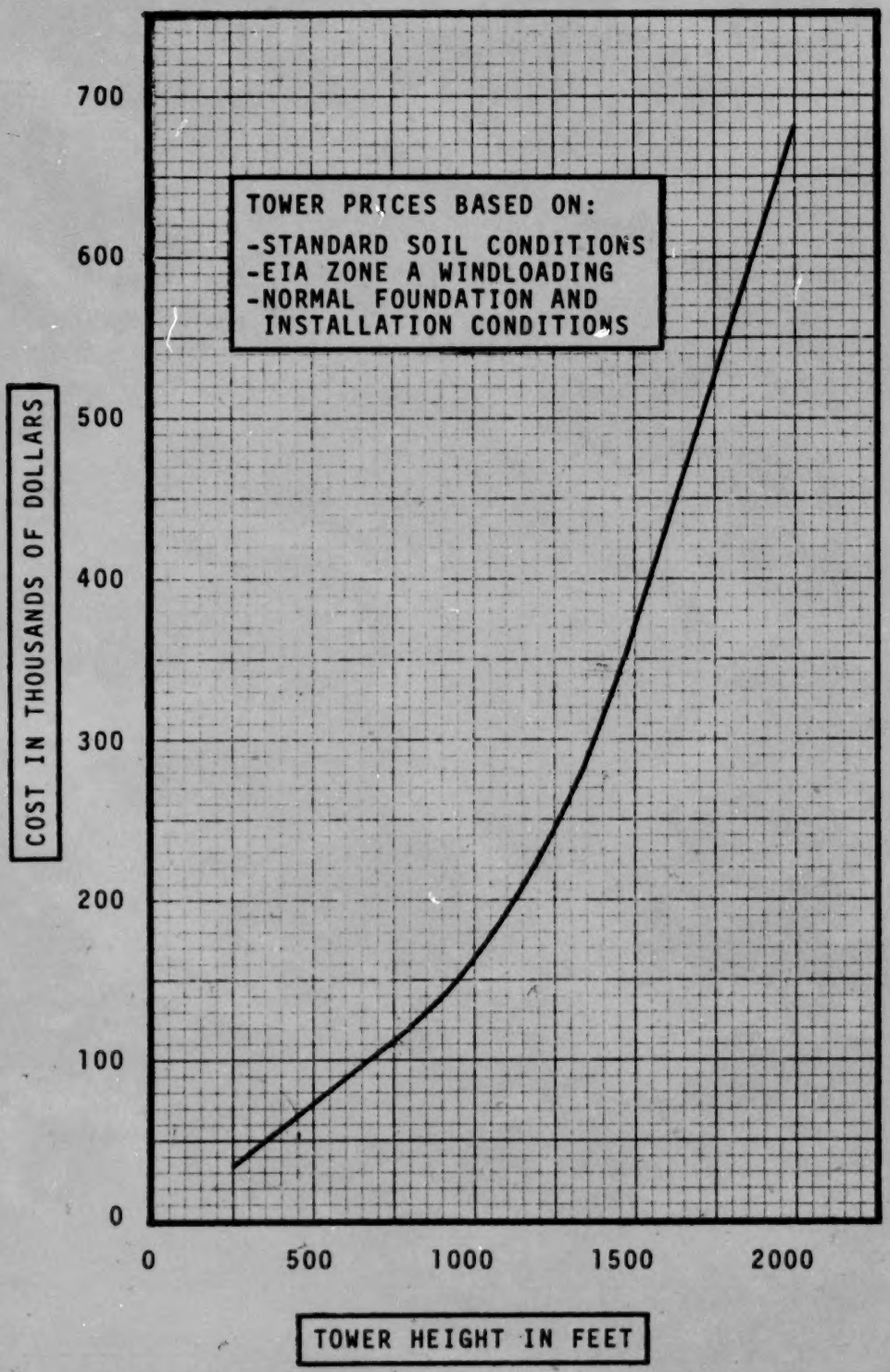


FIGURE 6: TOWER COST AS A FUNCTION OF TOWER HEIGHT

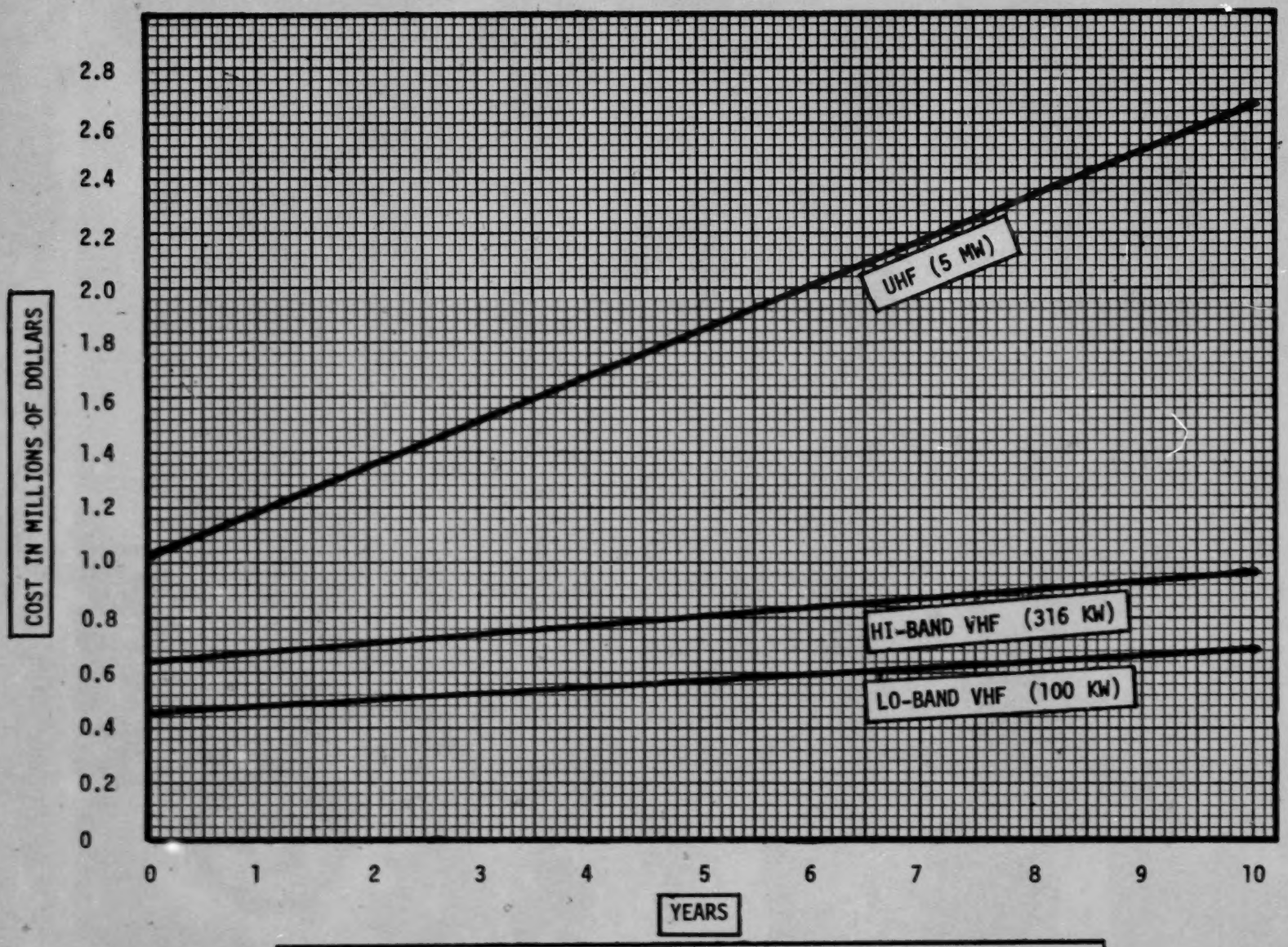


FIGURE 7: CONSOLIDATED CAPITAL COST AND TEN-YEAR OPERATING COST FOR FULL FACILITIES VHF AND UHF TRANSMITTER PLANTS

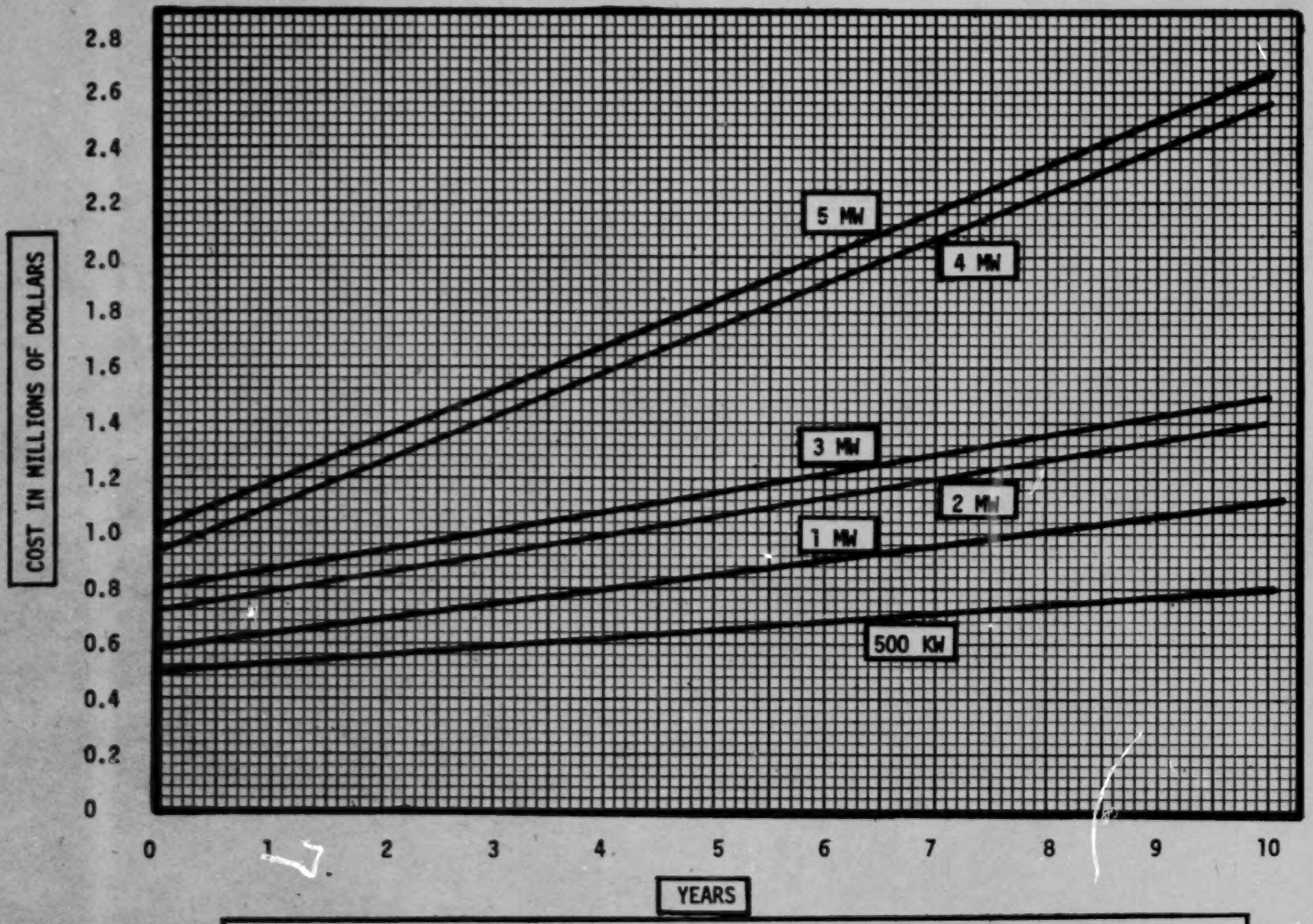


FIGURE 8: CONSOLIDATED CAPITAL COST & TEN-YEAR OPERATING COST FOR 500 KILOWATT THROUGH 5 MEGAWATT UHF TRANSMITTER PLANTS

SECTION 3

## PROPAGATION PATH/RECEIVING ANTENNA FUNDAMENTALS

For reasons which will become more apparent later, it is not convenient to discuss some of the significant fundamentals of VHF-UHF propagation and receiving antenna fundamentals separately.

Accordingly, these two elements of the total system are combined for a preliminary treatment in this section. This section is to be followed by some additional discussion of receiving antenna concepts of fundamental importance.

The propagation characteristics* of VHF (54 to 216 mHz) and UHF (470-806 mHz) signals are perhaps the least understood aspect of the VHF-UHF system problem. The FCC provides charts for predicting the signal strengths in dB above one microvolt/meter at a receiving antenna elevation of 30 feet above ground level as a function of ERP and transmitting antenna elevation above average terrain for any selected distance. Virtually all engineers familiar with the problem of predicting the service areas of both VHF and UHF television stations recognize the "real-world" shortcomings of the FCC F(50,50) charts as a reliable prediction tool. Furthermore, the chart for the UHF channels (identified as Figure 9 in Part 73.699 in the FCC Rules and Regulations) is, at best, only applicable when the assumed terrain conditions exist throughout the projected service area and when terrain conditions beyond 10 miles from the transmitter site are similar to the 2 to 10-mile distance used for height above average terrain determination. Additionally, the use of this chart yields questionable results for distances in excess of thirty miles from the transmitter site.

When the FCC issued the Sixth Report and Order in 1952, an adequate data base on UHF field performance did not exist. Consequently, the Commission exercised the expedient of adapting the Low-Band VHF F(50,50) chart to UHF, by simply

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* This section is not intended to be a comprehensive treatment of the principle of VHF-UHF signal propagation. Instead, this section deals only with two aspects of the subject believed to be of particular interest to practicing broadcast TV engineers.

redefining the City Grade, Grade A, and Grade B contours in terms of higher signal levels. For receiving sites within "line of sight" of the transmitter, this adaptation of the Low-Band VHF curves to UHF was not as arbitrary as it may seem; since, as will be shown later in this section, the free space field strength in microvolts per meter diminishes with distance, but is essentially frequency independent. Beyond "line of sight" however, due to obstruction losses, the Low-Band VHF curves do not accurately depict expected UHF performance.

As far back as 1952 - without benefit of the vast field experience available today - the Commission recognized many of the shortcomings of UHF relative to VHF that we know so well today. For example, the FCC definition for UHF Grade B service requires a UHF signal strength in dBu at the receiving antenna 17 dB greater than low-band VHF and 8 dB greater than high-band VHF.[3] In a further effort to reduce the disparity between UHF and VHF performance the FCC authorized the use of an effective radiated power of 37 dBk (5 megawatts) for UHF as compared to the maximum of 20 dBk (100 kw) for low-band VHF and 25 dBk (316 kw) for high-band VHF. Furthermore, the FCC permitted UHF stations in all zones to operate at full ERP with transmitting antenna heights up to 2000 feet above average terrain.

There is little doubt among knowledgeable engineers that new propagation prediction curves are needed for both VHF and UHF. Furthermore, techniques which are acceptable to the Commission must be developed and adopted for prediction of coverage under rough terrain conditions. In the meantime, a better understanding among station engineers of the significant propagation differences between VHF and UHF as applied to television broadcasting, is essential. This is the objective of this section.

In an effort to side step - or "cut-off-at-the-pass" all arguments dealing with the relative merits of the propagation curves which are currently part of the rules and new curves which have been considered under Docket 16004, this section will deal with VHF and UHF propagation differences on the basis of the known physical facts of electromagnetic wave propagation which are treated in any good textbook.

First and foremost, the attenuation of electromagnetic wave radiation in the frequency range from 54 mHz (beginning of low-band VHF) to 806 mHz (the upper limit of the current UHF broadcast band) is essentially independent of frequency!

This statement is in conflict with the well known equation for free-space attenuation which appears in virtually all engineering handbooks and states that the attenuation between an isotropic radiator and a collector is an inverse function of distance and frequency! For convenience, this equation is reproduced below.[4]

$$P_T/P_R = (4.56 \times 10^3) F^2 D^2 \qquad (1)$$

Where $P_T/P_R$ is the ratio of power transmitted to power received, F is in megahertz, and D is in statute miles.

Expressed in the more familiar decibel form, equation (1) becomes:

$$\alpha(dB) = 36.6 + 20 \log F + 20 \log D \qquad (2)$$

It might be rather surprising to learn that equation (2) does not represent the physical facts of free-space attenuation.

Equation (2) is a convenient formula developed by engineers for use by engineers and may be used only in conjunction with complementary engineering concepts for specifying the directive gain of transmitting and receiving antennas as so many decibels above an isotropic or half-wave dipole reference antenna.*

In the next section it will be shown that the effectiveness of both the reference isotropic antenna and the half-wave dipole obviously decreases with increasing frequency. Thus the effectiveness of gain antennas also

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* Since the gain of a reference half-wave dipole antenna is 2.2 dB above a reference isotrope, the free-space loss given by equation (2) must be reduced by 2.2 dB if a dipole reference is used for the receiving antenna.

decreases with frequency in a manner which is not revealed by the antenna gain expressed as so-many dB above a reference antenna since the effectiveness of the reference antenna is in fact changing with frequency. Therefore, it is convenient to attribute the increased losses to the propagation path! Hence, the frequency term in equation (2).

At this point it must be clearly understood that when the propagation path is located near the surface of the earth (as it always is for television broadcasting), additional losses must be added at both VHF and UHF frequencies to the path attenuation given by equation (2). It is the relative influence of these losses, due to earth curvature, departures from smooth earth curvature conditions caused by rough or rugged terrain, and meterological conditions in the troposphere which contributes to the total effective path attenuation differences between VHF and UHF.

Going back to fundamentals, if the propagation path is essentially independent of frequency, how is the performance of the half-wave receiving antenna, as a device for "converting" volts per meter into output volts, calculated?

The simplified form of the equation for accomplishing this is:

$$V = [\frac{\lambda}{2\pi}]\varepsilon \qquad (3)$$

Where V is the output volts (or microvolts) across the 75-ohm termination, $\lambda$ the wavelength in meters, and $\varepsilon$ the field intensity in volts (or microvolts) per meter, parallel to the half-wave dipole.

The bracketed quantity [ $\lambda/2\pi$ ] has the dimension of length (meters) and is frequently referred to as the "effective length" of a half-wave dipole antenna.* Equation (3) can, of course, be expressed in terms of frequency instead of wavelength.

---

* Folded dipoles are fundamentally 75-ohm dipoles with an integral 1:4 impedance transformer to increase the output impedance to 300 ohms which also raises the output voltage across the 300 ohm termination by a factor of two.

In terms of frequency:

$$V = [\frac{300}{2\pi F}]\varepsilon \qquad (4)$$

Where F is in mHz and V and $\varepsilon$ are as defined in equation (3).

It is clear from an examination of equation (4) that the antenna output voltage is an inverse function of frequency.* Therefore, equation (4) cannot be used in conjunction with path loss equations such as equation (2) which also include a frequency term to calculate the receiving antenna terminal output voltage.

The systems engineer is thus faced with two equivalent methods of predicting system performance and the concepts developed for use with each method must not be intermixed.

The two equivalent methods referred to are:

Method A

Calculation of the antenna output voltage as a function of the antenna gain expressed in decibels above a reference isotropic or half-wave dipole and the propagation path loss in terms of the well-known equation.

$$\alpha(dB) = 36.6 + 20 \log D + 20 \log F.$$

This is the convenient engineering procedure which does not represent the physical facts in that the frequency function is included in the path attenuation equation.

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* Equation (4) may also be expressed in decibels in the form:

$$DBU = 33.6 + dbu - 20 \log F.$$

Where: DBU is the antenna output signal in db above one microvolt, dbu is the signal strength in db above one microvolt per meter, and F is the frequency in mHz.

Method B

Calculation of the antenna output voltage in terms of the parallel component of the signal strength in volts per meter* and the propagation path loss in terms of the equation:

$$\alpha(dB) = 75 + 20 \log D. \qquad (5)$$

In this method the frequency function is included in the receiving antenna where it belongs and not in the propagation path as in Method A.

Note that in this form of the attenuation equation, the constant term has been increased from 36.6 to 75 and that the frequency dependent term is absent. Also note that with Method B, the frequency (or wavelength) function has been placed where it belongs - in the receiving antenna, as given by equations (3) or (4).

Although two alternative methods** are available to calculate the signal level available at the output terminals of a receiving antenna, only one of the methods (Method B) is descriptive of the physical facts and that is the "effective length" and hence sensitivity of the antenna which varies with frequency and not the propagation path attenuation. Restated, the effectiveness of a receiving antenna decreases with increasing frequency - even though the advertised gain in decibels above a reference isotropic or half-wave dipole is the same at all frequencies! Consequently, the gain of a receiving antenna expressed in decibels above a reference dipole must increase with frequency merely to provide continued output voltage for constant field intensity in volts per meter parallel to the receiving antenna. The required decibel gain increase is 6 dB each time the operating frequency is doubled and is given in the following equation:

$$\Delta dB \text{ gain} = 20 \log (F_2/F_1) \qquad (6)$$

---

* New F(50,50) type curves based on the best engineering knowledge available to date and an adequate statistical base could be used to establish the field strength when used in conjunction with valid correction factors for unusual terrain conditions.

** See the Appendix for a numerical example of the application of Method A and Method B.

Where $F_2$ is the higher frequency at which the signal strength in volts per meter is the same as at a lower frequency $F_1$ and $\Delta$dB is the necessary increase in receiving antenna gain at a frequency corresponding to a higher UHF channel.

This fact, in combination with the increased antenna-to-receiver line loss at UHF and the higher noise figure of UHF tuners explains why the Commission - in recognition of the fundamental problems facing UHF broadcasting - made the wise decision to permit UHF broadcasting facilities to operate at an ERP up to five megawatts and transmitting height above average terrain up to 2000 feet in all zones without ERP restriction.

An important aspect of the VHF-UHF performance disparity deals with the propagation differences when terrain obstructions are located in the propagation path. The terrain obstruction may range from the well-known earth curvature (smooth obstruction) to rough terrain or may consist of man-made obstructions of various sizes and shapes in addition to the ubiquitious earth curvature phenomenon.

The effect of terrain and/or physical obstructions on the relative effect of propagation path losses can be illustrated by application of the well-known Bullington Curve.[5] This curve is shown in Figure 9.

For purposes of illustrating the application of the Bullington Curve to the relative VHF-UHF obstruction loss phenomena, the classic "knife-edge" obstruction is used since experimental data are available to confirm the theory.

Figure 10 shows the three classes of propagation paths: The unobstructed "optical path" condition; the "grazing path" condition; and the obstructed "shadow-path" condition. The "cigar-shaped" contour shown in the illustrations represents the "first Fresnel" zone. The Fresnel Radius "H" decreases with frequency, and can be calculated at any point along the path by:

$$H = 2280\sqrt{(d_1 d_2/D)\,\frac{1}{F}} \qquad (7)$$

Where H is the Fresnel radius in feet, $d_1$, $d_2$ the distance in miles to the point in question, D the total path length, and F the frequency in mHz.

Using the Bullington Curve shown in Figure 9, three obstruction loss curves as a function of obstruction clearance in feet can be developed with selected VHF and UHF TV channels as parameters. If the "knife-edge" obstruction is varied from plus 400 feet through zero to minus 400 feet, the variation of the obstruction loss $\beta$ for the VHF and UHF channels can be established and plotted. Curves of this type for VHF Channels 4 and 10, and UHF Channel 42 are shown in Figure 11.

Three fundamental conclusions may be reached by examination of these curves.

1. When the path is "optical", the knife-edge obstruction introduces <u>less</u> attenuation at UHF than at VHF.

2. When the path is "grazing", the knife-edge obstruction introduces equal attenuation for both UHF and VHF.

3. When the path is "shadowed", the knife-edge obstruction introduces significantly <u>more</u> attenuation at UHF than at VHF.

Some additional comment is in order with respect to Conclusion #1. In the development of Figure 11, the clearance criterion C/H in Figure 9 (the Bullington Curve) was restricted to a maximum value of +1. That is, obstruction clearance in the optical region was limited to no more than so-called "first Fresnel" clearance. For greater obstruction clearances (C/H greater than +1), both VHF and UHF attenuation will vary cyclically about plus or minus one dB with clearance as shown by the Bullington Curve. The magnitude of the cyclic variations will be essentially independent of frequency, however, the periodicity, or number of maxima and minima over a given clearance range will be greater for the shorter UHF wavelengths than for the longer VHF wavelengths.

The differences in obstruction loss in the shadow and optical region shown in Figure 11 for VHF and UHF propagation reveals an interpretation which, although interesting, is of little consolation now that the VHF and UHF assignment plan described in the Sixth Report and Order is 21 years old. Careful examination of the relative obstruction losses in the optical and shadow regions suggest that the Commission in 1952 should have assigned the

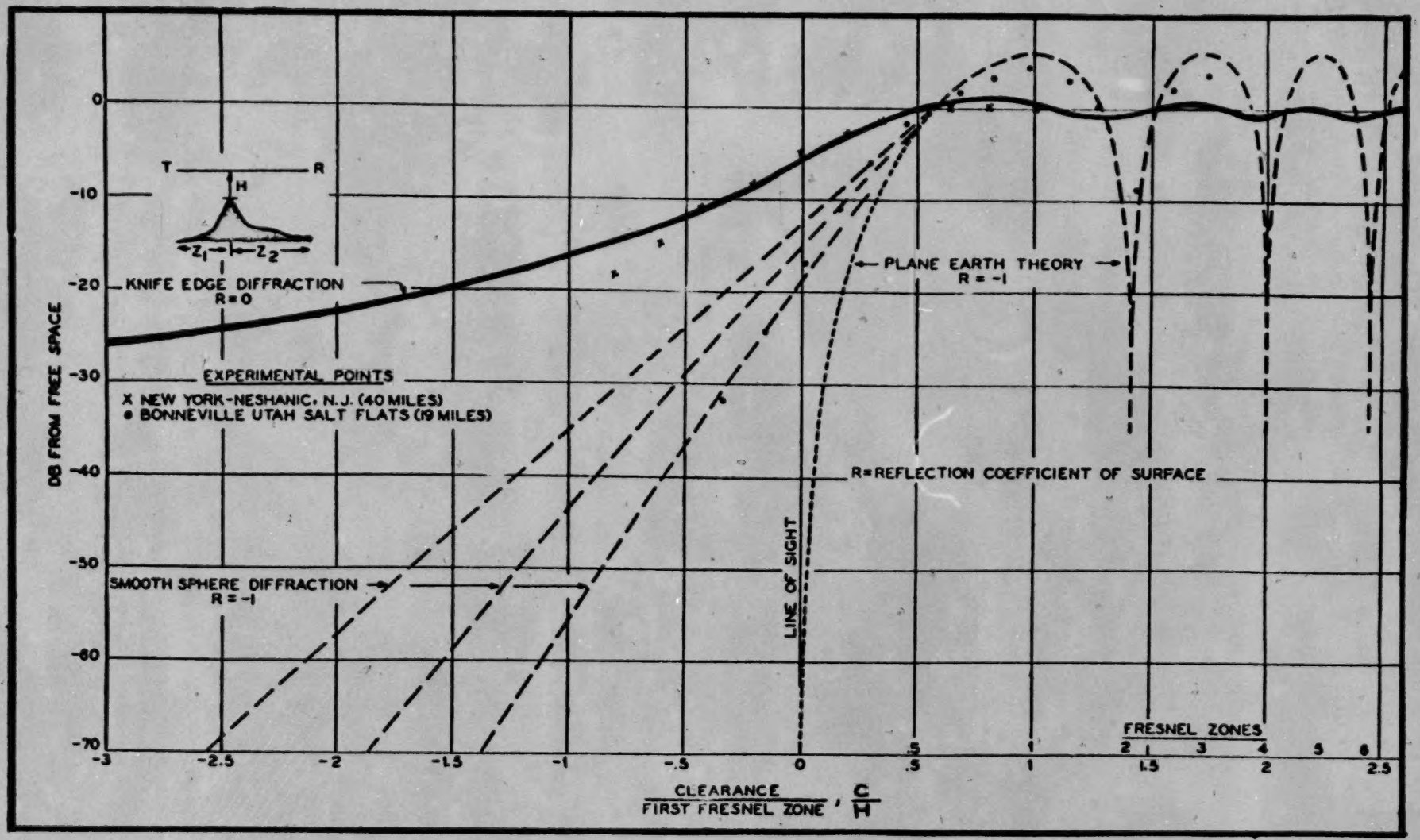


FIGURE 9: THE BULLINGTON CURVE

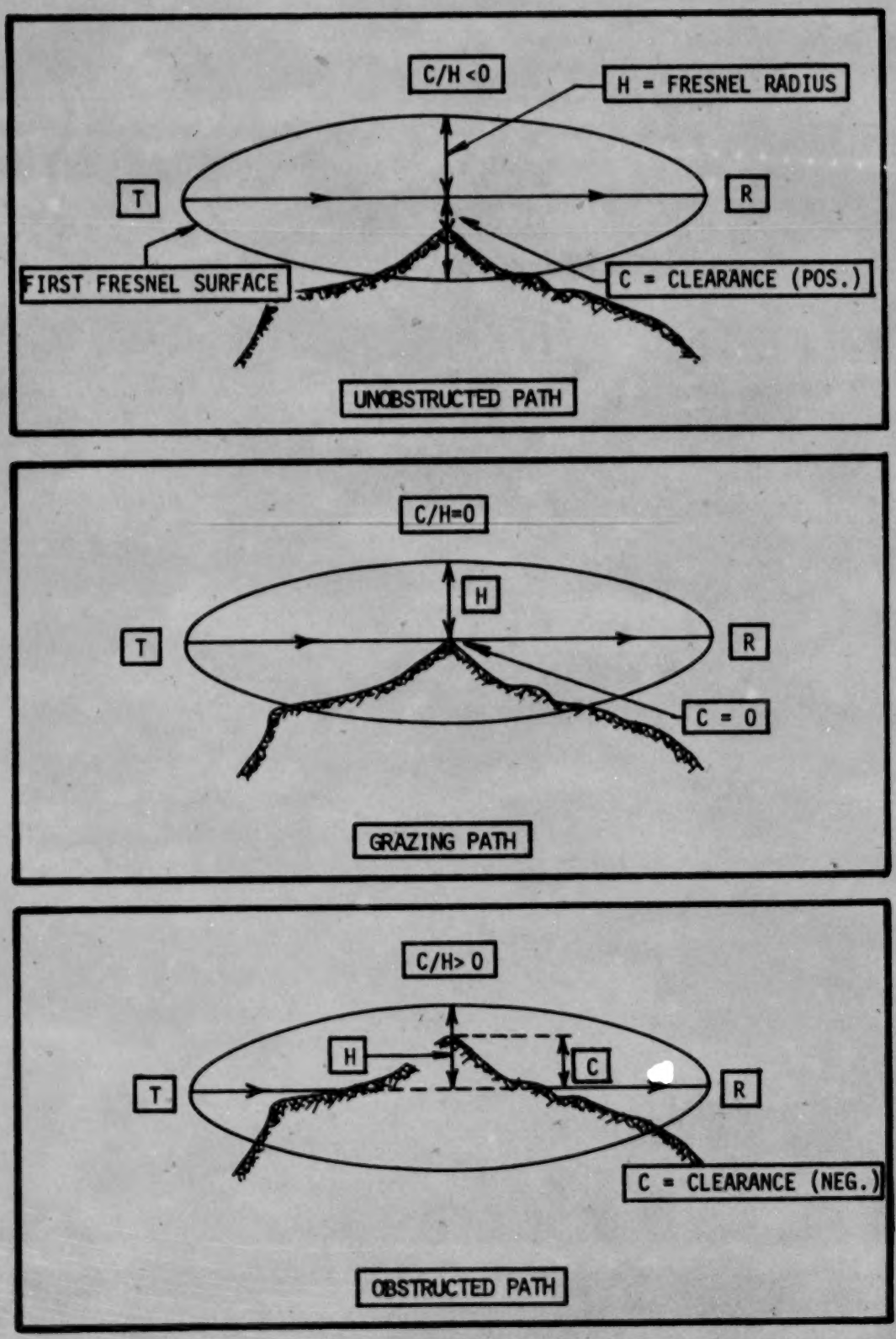


FIGURE 10: THREE PATH OBSTRUCTION CLEARANCE CONDITIONS

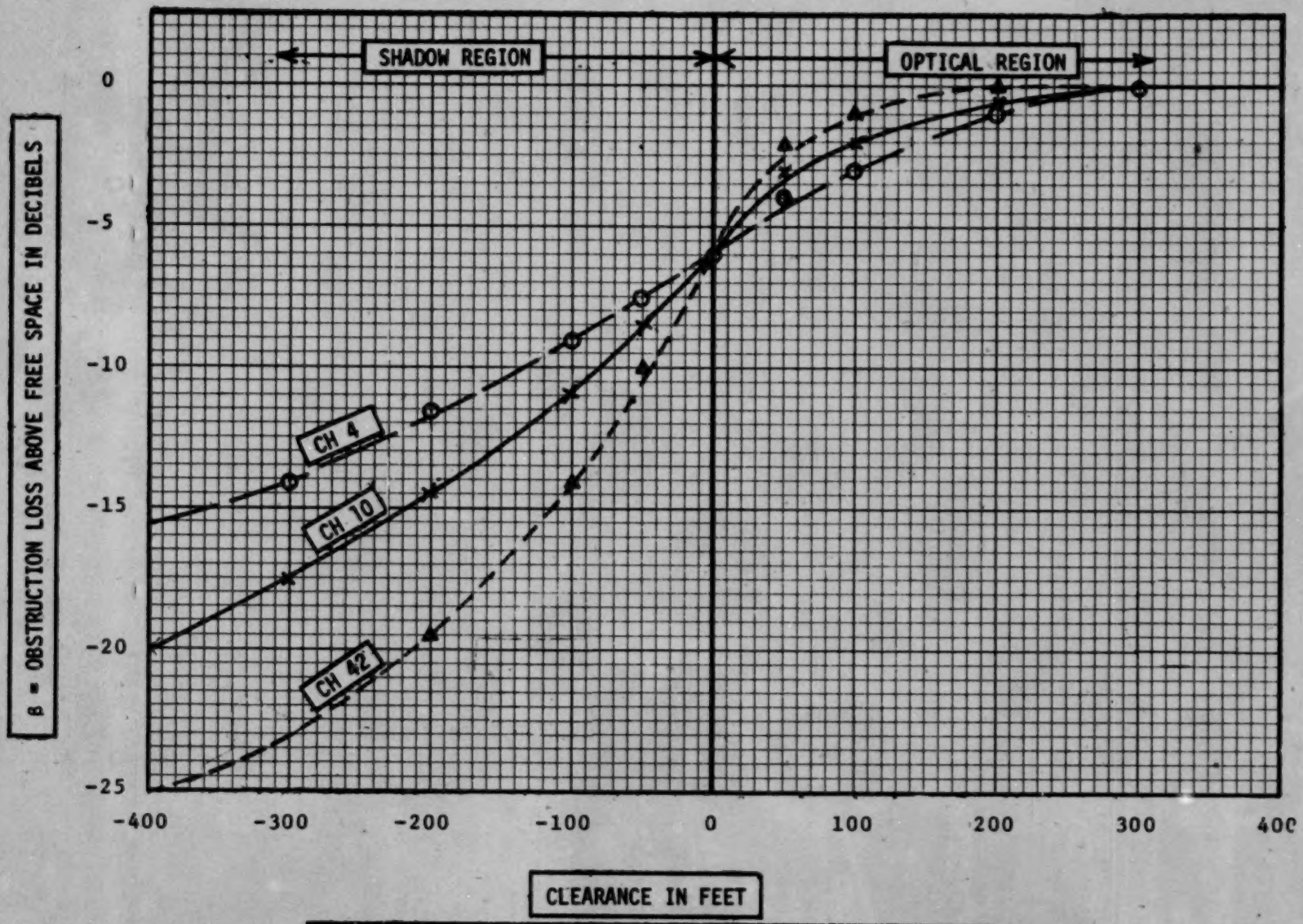


FIGURE 11: OBSTRUCTION LOSS FOR VHF CHANNELS 4, 10 AND UHF CHANNEL 42

UHF channels for activation in the flat areas of the U.S. (midwest, southeast, etc.), and the VHF channels to those areas of the U.S. which are characterized by rough terrain. Furthermore, the high-band VHF channels should have been assigned to those regions which exhibit moderate terrain roughness and the low-band VHF channels assigned to the mountainous regions characterized by the roughest terrain.

SECTION 4

RECEIVING ANTENNA FUNDAMENTALS CONTINUED

It has been shown in an earlier section of this report that the specification of receiving antenna performance in terms of dB gain above an isotropic antenna or a half-wave dipole is an engineering convenience which is not descriptive of the antenna's ability to convert the field strength in microvolts per meter parallel to the antenna elements into output microvolts available across the antenna output termination.

It is the objective of this section to elaborate on this point further through an alternate approach and to "drive home" the fundamental point that the performance of receiving antennas can be expressed more realistically in terms of "effective capture area".

The power density associated with a passing electromagnetic wave front is given by the equation:

$$\rho = \varepsilon x H \qquad (1)$$

Where $\rho$ is watts per square meter, $\varepsilon$ is the electric field strength in volts per meter, and H is the magnetic field strength in amperes per meter. Thus, the total power P passing through a given area (one square meter, for example) is given by the following integral expression:

$$P = \int_0^A (\varepsilon x H)da \qquad (2)$$

For a uniform field in the far field, or Fraunhofer region, equation (2) can be simplified to the following product.

$$P = \varepsilon H A \qquad (3)$$

A receiving antenna cannot "reach out" beyond its physical boundaries to abstract energy from a passing electromagnetic wavefront. Thus, the maximum possible energy a receiving antenna can "collect" is related to its absolute

physical cross-section parallel to the electromagnetic wavefront. Restated, this means that if a UHF antenna is to exhibit the same effectiveness as a given VHF antenna, it must exhibit comparable physical dimensions - not in terms of wavelength, but in terms of absolute physical size.

A convenient relationship can be established between the directive gain of a receiving antenna and its "effective aperture area" as follows:

The power gain ratio of any antenna may be expressed by the fundamental equation:[6]

$$G = [4\pi/\lambda^2]A \qquad (4)$$

Where G is the power gain ratio expressed as a dimensionless numeric referred to an isotropic antenna, A is the effective area, and $\lambda$ is the operating wavelength in the same units as A. This relationship clearly reveals that antenna gain is proportional to the effective area and inversely proportional to the square of the operating wavelength. This conclusion is consistent with the view expressed in the path propagation section that the propagation path attenuation is essentially independent of frequency and that it is the antenna effectiveness which decreases with increasing frequency.

The effective apertures of two basic reference antennas may be established from another set of basic facts:[7]

| Antenna Type | Power Gain Ratio (G) |
|---|---|
| Isotropic | 1.0 |
| Elementary dipole (doublet) | 1.5 |
| Half-wave dipole | 1.64 |

Thus, for the isotropic reference:

$$G = 1 = [4\pi/\lambda^2]A, \text{ or}$$

$$A = \lambda^2/4\pi$$

For the half-wave dipole:

$$G = 1.64 = [4\pi/\lambda^2]A, \text{ or}$$

$$A = 1.64\ [\lambda^2/4\pi] \qquad (5)$$

A comparison of effective areas for half-wave reference dipoles at VHF Channel 2 and UHF Channel 69* can be a little jarring. For example:

The wavelength at Channel 2 is:

$$300/F_{mHz} = 300/57 = 5.26 \text{ meters}$$

The wavelength at Channel 69 is:

$$300/803 = 0.37 \text{ meters.}$$

Substituting in equation (5):

A (Ch 2) = 3.61 sq. meters.
A (Ch 69) = 0.017 sq. meters.

The ratio of the areas is:

$$3.61/0.017 = 212:1$$

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* Admittedly a worst case, but nevertheless a possible situation.

Thus it should no longer be surprising that the intercepted signal power (hence the useful TV signal in microvolts available at the output terminals of the antenna) is so low at UHF frequencies compared to VHF frequencies for equal field intensity adjacent to the antenna.

The gain difference in decibels (ΔdB) can be readily calculated by taking 10 times the common log of the effective area ratio.*

The result is:

$$\Delta dB = 10 \log (3.61/0.017) = 23 \text{ dB}$$

The same result would have been obtained if the figures corresponding to Channel 2 and 69 had been substituted into equation (6) given on page 16. Accordingly, equation (6) can be used to construct a family of curves depicting the gain increase in decibels (ΔdB) required to provide a constant effective length** for all UHF channels relative to VHF channels 2 through 13. A family of curves depicting this relationship is shown in Figure 12.

Since VHF antennas of the type used beyond the Grade A contour exhibit gains above a reference dipole of the order of 6 dB for low-band VHF and about 9 dB for high-band VHF[8], it appears that UHF antennas must exhibit gains of the order of 20 dB to provide effective aperture areas comparable to the average gain of typical all-channel VHF antennas. Most UHF antennas in the same category as the 6 and 9 dB VHF antennas, generally exhibit gains of the order of 10 to 12 dB. At first glance, it would appear that it is only necessary for a UHF antenna to exhibit physical dimensions comparable to the dimensions of a VHF antenna. If a "super array" of individual UHF antennas were constructed, with adequate spacing between the antennas to minimize interaction effects, it is possible that the necessary gain increase could be achieved.

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* Conversely, the effective area increase for an antenna of any known gain in dB can be obtained by multiplying the area of the reference antenna by the appropriate antilog of the antenna gain. For example, an antenna with a gain of 6 dB will have an effective area equal to antilog (6 dB/10), or four times that of the reference antenna.

** A constant effective length is required to provide constant output voltage over the VHF-UHF bands as a function of constant field strength parallel to the polarization axis of the receiving antenna.

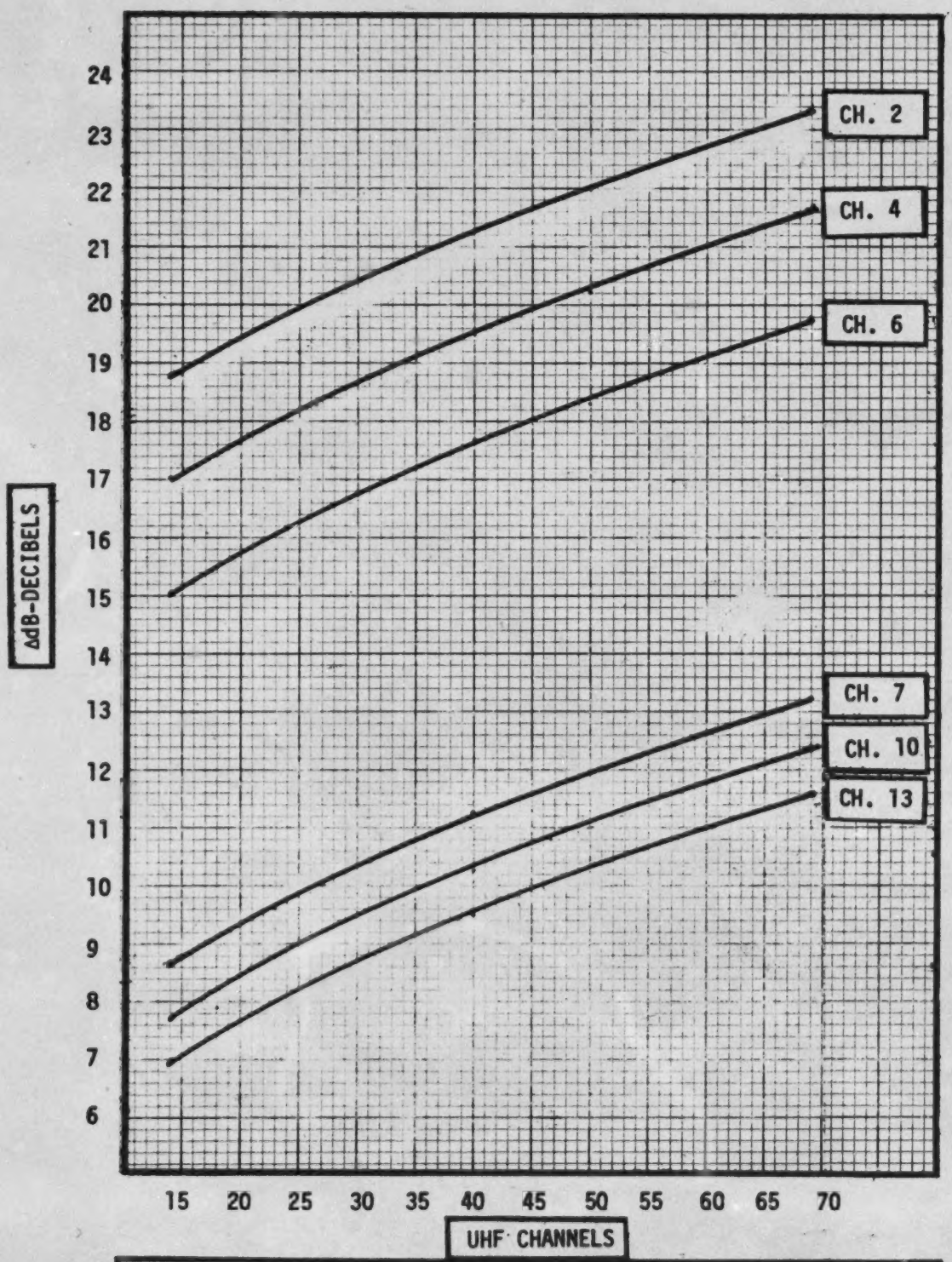


FIGURE 12: ADDITIONAL UHF ANTENNA GAIN REQUIRED FOR CONSTANT EFFECTIVE LENGTH AS A FUNCTION OF VHF AND UHF CHANNEL

It has been suggested that the SIA (Subminiature Integrated Antenna) concept may be a solution to the problem of small capture areas exhibited by UHF TV antennas. SIA's (also known as "active" antennas) are characterized by elements appreciably less than a half wavelength which provide performance comparable to their full-size counterparts. The comparable overall sensitivity of these antennas is achieved by providing the antenna with a low-noise solid-state preamplifier as an integral part of the antenna. This approach is a feasible technique for increasing the effective sensitivity (greater output voltage for a given field strength) of special-purpose antennas (military or surveillance antennas for example) which must be characterized by small size and thus cannot be constructed with resonant half or quarter wavelength elements. Although UHF TV antennas are not subminiature antennas as are SIA's, the idea of incorporating solid-state active elements as an integral part of the antenna to increase the output signal level is a good one. However, it should be recognized that such active elements constitute nothing more than a preamplifier and that it makes little difference whether the preamplifier is an integral part of the antenna or whether it is a conventional low-noise preamplifier installed at the antenna output terminals.

Unfortunately, there is another antenna law legislated by Mother Nature which tells us that as the gain of an antenna is increased the beamwidth decreases! The exact relationship varies with the type of antenna. For Yagi antennas, the approximate relationship between antenna gain in dB (above a reference half-wave dipole of course) and beamwidth between half-power points (-3 dB) is shown in Figure 13. Examination of this curve reveals that a gain of 20 dB will result in a 3 dB beamwidth of four degrees. A few moments of reflection on the torsional characteristics of the typical UHF antenna support - particularly when subjected to moderate wind gusts - would suggest that a beamwidth no greater than four degrees would result in significant variations in output signal from the antenna and hence variations in picture quality as the antenna whips around in the wind. Such practical considerations appear to limit the minimum beamwidth to about 10 degrees. Thus, the corresponding maximum antenna gain would be about 16 dB.

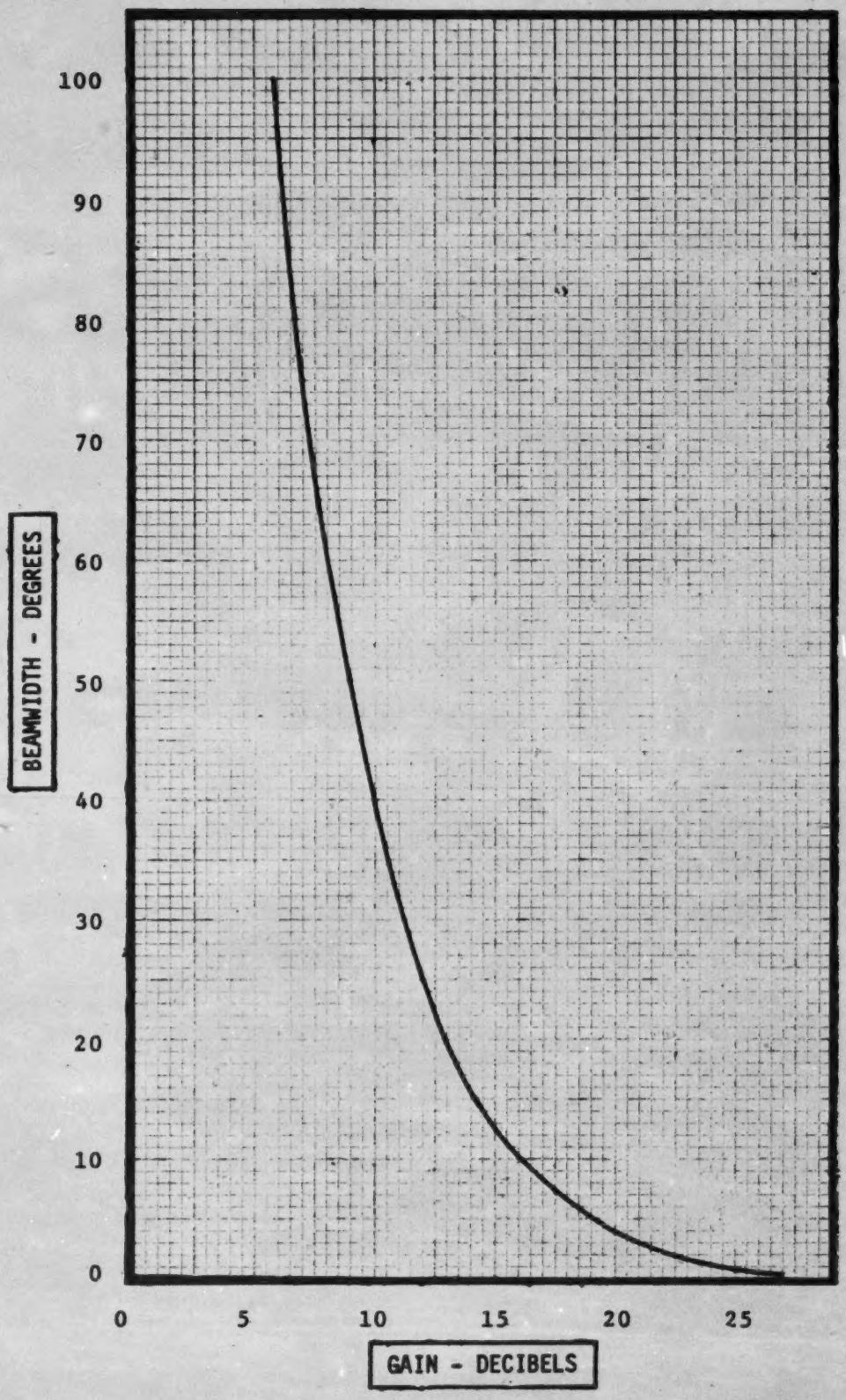


FIGURE 13: HALF POWER BEAMWIDTH AS A FUNCTION OF GAIN FOR YAGI UHF RECEIVING ANTENNAS

## SECTION 5

## THE RECEIVING ANTENNA TRANSMISSION LINE

The signal voltage available across the termination of either a VHF or UHF antenna must be conducted to the input terminals of the receiver tuner with minimum signal attenuation. It is the objective of this section to examine the relative transmission line losses of three basic line types in common use with receiving systems at VHF and UHF frequencies.

Three basic types of antenna-receiver transmission lines are available. They are:

1. Ordinary unshielded 300-ohm flat ribbon.
2. Shielded 300-ohm balanced line.
3. Coaxial cable (with or without 75/300 balun transformers, depending on the antenna or receiver in use).

A comparison of the attenuation in dB per 100 feet for the three basic types of transmission lines[9] is shown in Figure 14. Most TV receiving systems (that employ an outside antenna) generally employ conventional unshielded 300-ohm balanced lines. The attenuation figures shown for the lines are based on the assumption that the unshielded 300-ohm line is clean, dry, and has been properly installed.

Such lines are essentially "open" transmission lines. As a consequence, the electromagnetic field associated with the TV signal voltage and currents is not confined to the immediate boundaries of the conductors. Thus, the overall attenuation is critically influenced by the presence of dirt and moisture on the transmission line dielectric as well as the presence of foreign objects - particularly metal - within a radius of about six inches from the line. Dirt and moisture, and the proximity of metal near the line does not impair the performance of shielded 300-ohm line and coaxial cable.

The possible effect on the attenuation of unshielded 300-ohm line due to the cumulative effects of dirt, moisture and poor installation practices which are quite common in the average UHF antenna installation, is shown at the bottom of Figure 14. It is obvious that the condition of unshielded 300-ohm lines and the installation practices followed are crucial to the satisfactory operation of unshielded 300-ohm lines.

Most typical outside antenna installations involve the use of antenna-to-receiver transmission lines approximately 50 feet long. Therefore, the average attenuation differences, $\Delta dB(L)$, for VHF and UHF lines can be tabulated as follows:

| | DECIBELS | | | |
|---|---|---|---|---|
| | UNSHIELDED 300-OHM | SHIELDED 300-OHM | 1/2"COAX 75-OHM | 1/4"COAX 75-OHM |
| CH 4/CH 42 | 1 | 2 | 2.5 | 3 |
| CH 12/CH 42 | 0.75 | 1 | 1.25 | 1.5 |

It is also apparent from the tabulation that - at least for 50' line lengths - no substantial reduction in VHF/UHF disparity can be realistically expected in the antenna-to-receiver downlead <u>if</u> the downleads are in good condition and properly installed. Also, it would appear from the curves and the tabulation that the simple unshielded, 300-ohm line - if in good condition and properly installed - exhibits the lowest attenuation differential for any VHF-UHF channel combination. However, it must also be recognized that the unshielded 300-ohm line is the most susceptible to the degrading effects of dirt, moisture, and poor installation practices and is thus <u>less likely</u> to maintain the possible performance advantages over the long haul.

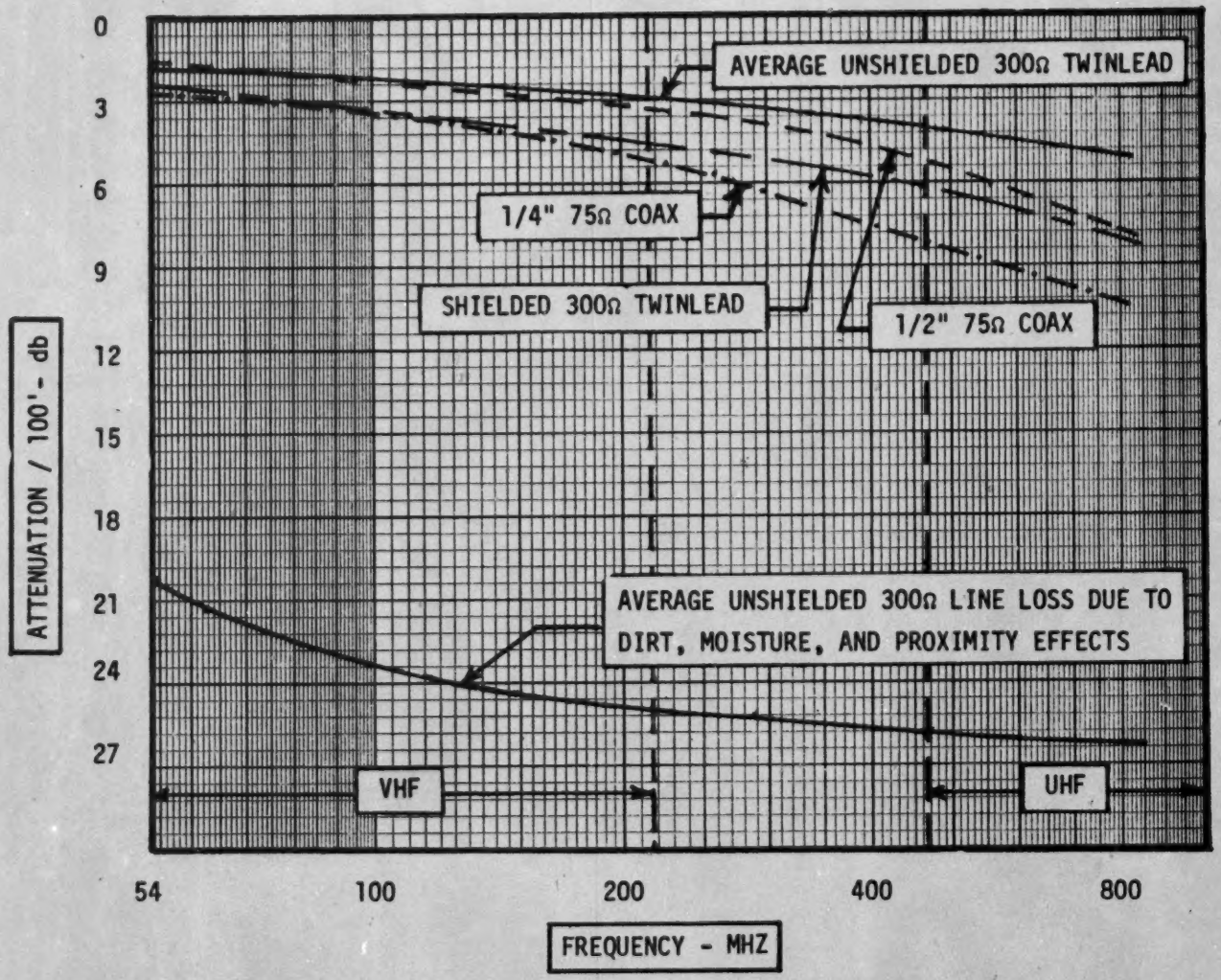


FIGURE 14: ATTENUATION OF THREE TYPES OF RECEIVING TRANSMISSION LINES AS A FUNCTION OF FREQUENCY

SECTION 6

## THE RECEIVER NOISE FIGURE

One of the most important parameters of the TV transmitting/receiver system, which establishes the picture quality as displayed -on the screen of a typical television receiver, is the carrier-to-noise ratio (C/N) available at the input terminals of the TV tuner. For a given receiver sensitivity, the absolute value of the signal level at the tuner input terminals establishes the picture contrast while the noise level* generated by the tuner establishes the so-called "snow level" which tends to obscure the picture content. If the C/N at the receiver input is inadequate, the displayed picture in terms of "contrast/snow" ratio cannot be improved since increased receiver gain will amplify the noise as well as the signal.

A comparison of VHF and UHF tuner noise figures (and hence C/N ratio for equal signal level at the tuner input) is very revealing. Figure 15 summarizes the the average maximum and minimum values of VHF and UHF noise figures based on data contained in the references cited.[10]

The values shown are for the majority of TV receivers in the homes of viewers today.**

It is painfully apparent that one of the most significant VHF-UHF performance gaps (that is correctable by the application of modern engineering technology) is due to the relatively poor performance of the typical UHF tuner compared to the typical VHF tuner.

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* Noise or interference levels originating from sources other than the noise level generated in the "front end" of VHF and UHF tuners are not treated in this report. External noise sources at VHF and UHF frequencies are generally masked by the relatively high noise levels internally generated in TV tuners.

** These figures should not be interpreted to suggest that UHF tuners currently going into production or undergoing development in the laboratories of tuner manufacturers exhibit noise figures no better than those currently in the field.

Most significant in Figure 15 is the large spread between the maximum and minimum values of the Noise Figures in the UHF band. Also it should be noted that Noise Figures below 10 dB can be achieved! Therefore, one of the first objectives of the tuner manufacturing industry should be to tighten the manufacturing tolerances and quality-control procedures to reduce the maximum values of the Noise Figure in production tuners to no more than 15 dB and preferably as low as 13 dB. This would reduce the large spread currently encountered and reduce the performance differences between UHF receivers. The current maximum UHF noise figure requirements as expressed in Part 15 of the Rules is 18 dB. A maximum Noise Figure of 18 dB may have been representative of the state of the art in 1964 when the all-channel legislation was drawn up, but it is hardly representative of the design and production capabilities of the tuner manufacturing industry in 1973-74.

Perhaps the time is now at hand when all institutions dedicated to the improvement of UHF performance should collectively submit a formal petition to the FCC proposing that the 18 dB noise figure maximum stipulated by the current rules be reduced to a maximum of 15 dB and possibly as low as 13 dB. This would bring the performance of UHF tuners one step closer to that of VHF tuners in addition to comparable ease of tuning now required by the Rules.

In conclusion, it would be unfair to the tuner manufacturing industry if this report did not recognize that there is now a glimmer of hope in the form of recent developments. Some of the newer and more expensive television receivers are now available with pushbutton varactor tuning whereby <u>all</u> of 20 or more buttons can be conveniently pre-tuned in the field to any VHF <u>or</u> UHF channel. This development achieves the goal of comparable ease of tuning. Hopefully, the next step will be comparable performance.

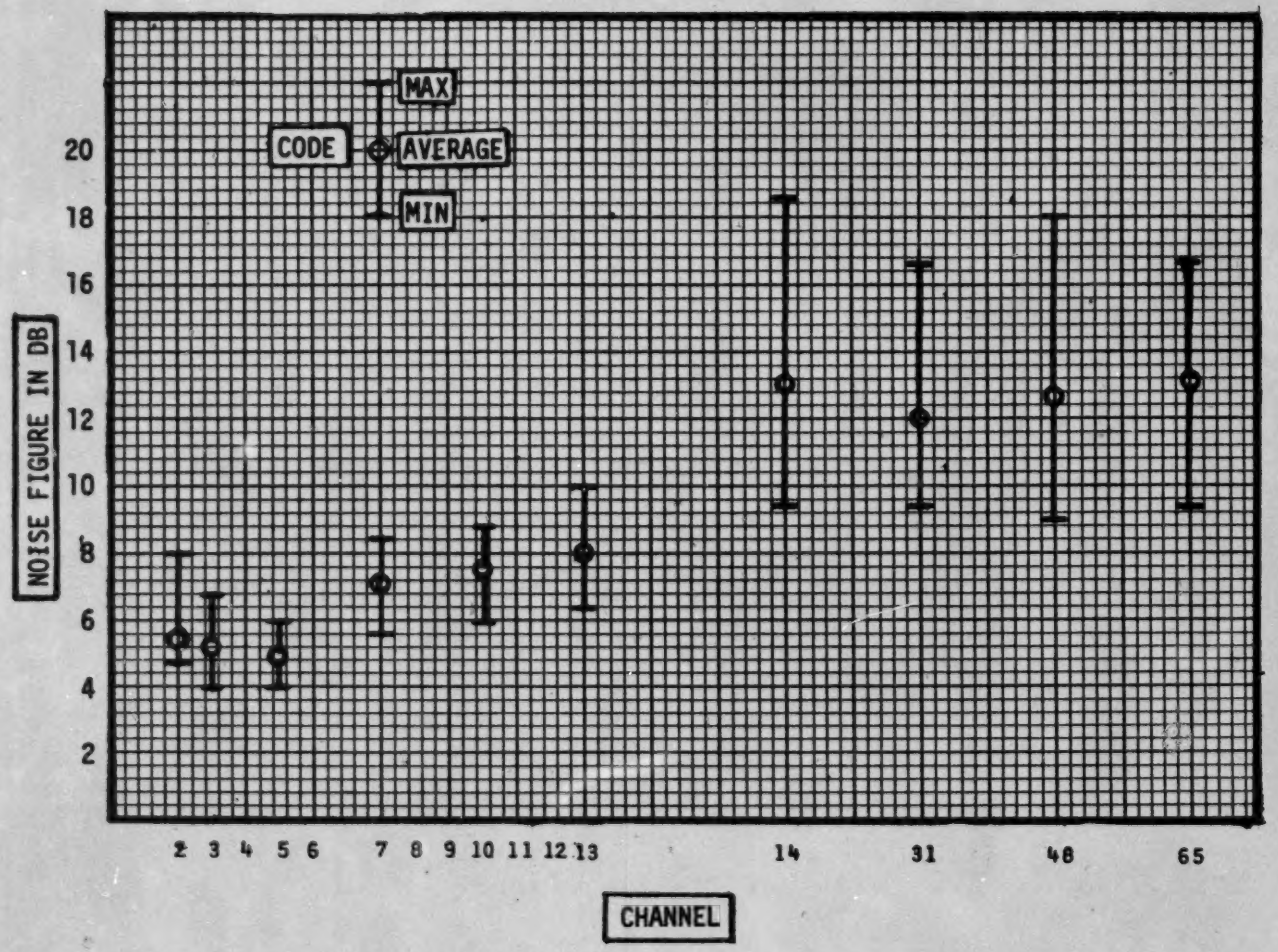


FIGURE 15: MEASURED NOISE FIGURES OF A GROUP OF 100 TELEVISION RECEIVERS

## SECTION 7

## COMPARISON OF THE OVERALL VHF-UHF SYSTEM PERFORMANCE

Any reasonable basis selected for objectively comparing the overall system performance of VHF and UHF systems may, in the final analysis, be branded as arbitrary and subjective. Obviously, an objective choice must be made for the particular VHF and UHF channels to be compared as well as a choice of effective radiated powers and antenna heights. For example, should the system comparison be made considering VHF Ch 2 and UHF Ch 69 (or even 83), or VHF Ch 13 and UHF Ch 14?

If the performance of low band VHF systems were to be compared with high-band VHF systems, the choice of channels would be almost obvious. It would undoubtedly be Channel 4 for low-band and Channel 10 for high-band by almost any criteria.

Unfortunately, the objective comparison of a UHF system with a VHF system is not quite so simple in that we have two groups of VHF channels and only one group of UHF channels.

A similar problem is encountered when considering a choice of effective radiated powers to be assigned to the channels to be compared. For VHF comparisons it would be the authorized maximum of 100 kw for low-band and 316 kw for high-band. Unfortunately, again, not many UHF stations - either commercial or non-commercial - are currently operating at the maximum authorized power of 5000 kw. The fundamental question here is: Should a selected UHF channel be compared with low-band VHF or high-band VHF and should the maximum authorized radiated powers be used in each case? Perhaps UHF systems should be compared with <u>both</u> low-band VHF <u>and</u> high-band VHF and the results presented without editorial comment.

For a defensible answer to these questions, reference is made to the statistics contained in the 1973-1974 edition of the TV Factbook recently released by Television Digest, Inc. Scatter diagrams showing the distribution of the effective radiated powers employed by non-commercial television stations and the distribution of antenna radiation centers above average terrain are shown in Figures 16 and 17. It appears reasonable to use an effective radiated power which occurs most frequently as a basis of comparison. The VHF and UHF channels chosen for comparison have been selected from the center of each band.

Accordingly, Channel 4, with an ERP of 100 kw for low-band VHF, Channel 10 with an ERP of 316 kw for high-band VHF, and Channel 42 with an ERP of 650 kw for UHF have been selected for making the system performance comparisons.

The system comparisons to follow are to be based on the application of the symbolic statement for C/N ratio in dB available at the input stage of the TV receiver as given in the Introduction of this report. This statement is repeated for convenient reference!

$$\Delta\ C/N = \Delta\ dB(T) + \Delta\ dB(P) + \Delta\ dB(A) + \Delta\ dB(L) + \Delta dB(NF).$$

Where the terms are defined as in the introduction.

The assumptions upon which the C/N ratio comparisons are to be based, are as follows:

| | |
|---|---|
| Transmitting Antenna Height: | Equal for both VHF and UHF. |
| Receiving Antenna Height: | Equal for both VHF and UHF. |
| Receiving Antenna Transmission line length: | 50 feet. |
| Distance between Transmitter and Receiver: | Equal for both VHF and UHF and well within the radio horizon so that relative terrain shadowing effects are not a factor.* |
| Terrain Conditions: | Average terrain considered to be relatively smooth so that relative terrain shadowing effects are not a factor.* |

C/N Ratio Comparison of Channel 42 with Channel 4

| | |
|---|---|
| ΔdB(T): | +8 dB [Ch 4: 100 kw, Ch 42: 650 kw] |
| ΔdB(P) or ΔdB(A): | -19 dB [-20 log (641 mHz/69 mHz)] |
| ΔdB(L): | -1.5 dB [Figure 14] |
| ΔdB(NF): | -7.5 dB [Figure 15] |
| Δ C/N | -20.0 dB |

---

* It has been shown in the propagation section that rough terrain which intercepts the direct line of sight path between the transmitting and receiving antenna will cause greater obstruction losses at UHF than at VHF. This is one area in which UHF systems are immutably inferior to VHF systems.

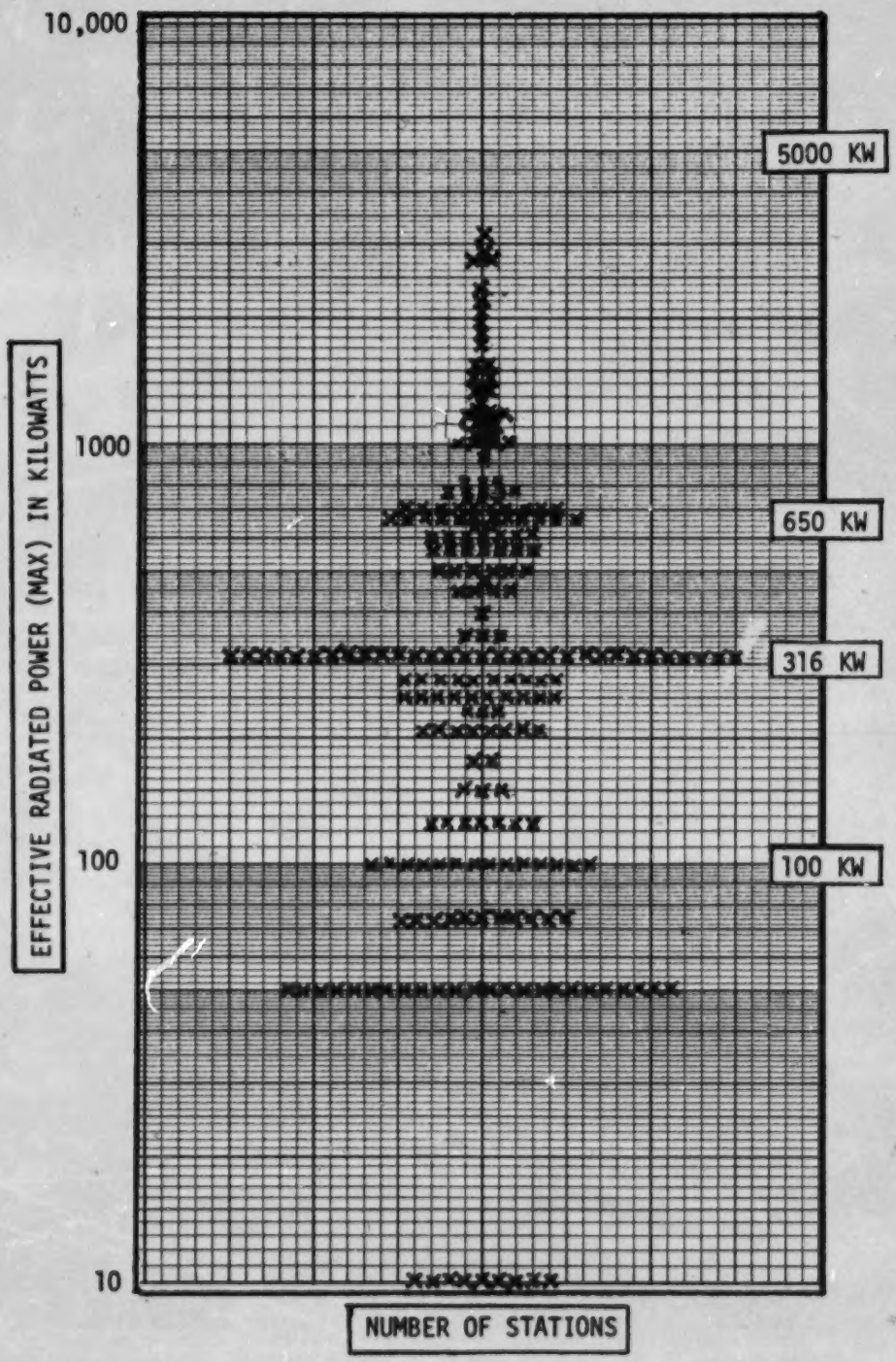


FIGURE 16: ERP DISTRIBUTION OF VHF & UHF PTV STATIONS IN THE CONTINENTAL U.S.
SOURCE: TV FACTBOOK 1973-74 EDITION

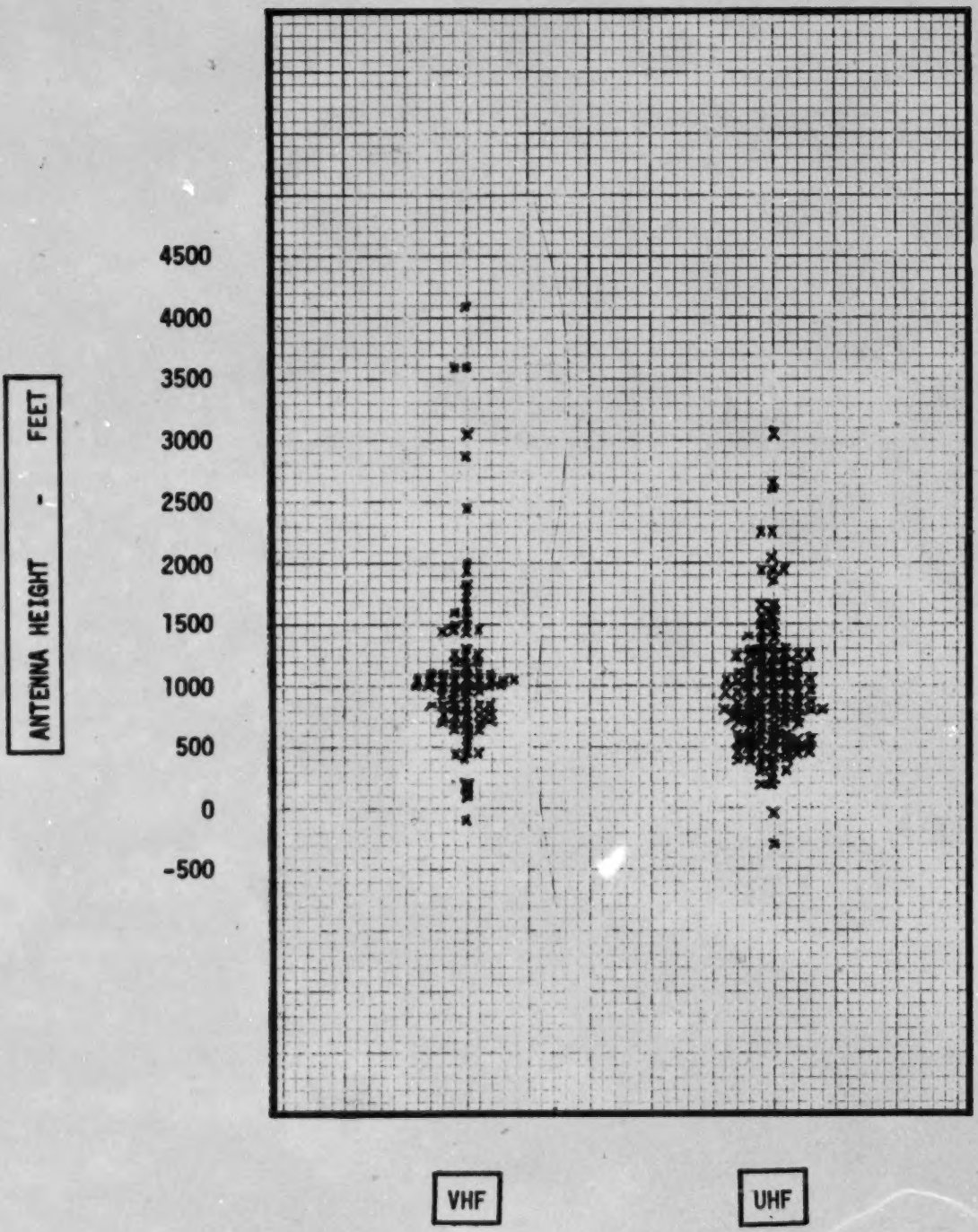


FIGURE 17: DISTRIBUTION OF ANTENNA HEIGHTS ABOVE AVERAGE TERRAIN OF PTV STATIONS IN CONTINENTAL U.S. SOURCE: TV FACTBOOK 1973-74

C/N Ratio Comparison of Channel 42 with Channel 10

| | | |
|---|---|---|
| Δ dB(T): | + 3 dB | [Ch 10: 316 kw, Ch 42: 650 kw] |
| Δ dB(P) or Δ dB(A): | -10 dB | [-20 log (641 mHz/195 mHz)] |
| Δ dB(L): | -1.5 dB | [From Figure 14] |
| Δ dB(NF): | -5 dB | [From Figure 15] |
| Δ C/N | -13.5 dB | |

A family of curves showing the calculated values Δ C/N for all UHF Channels 14 through 69 relative to VHF Channels 2, 4, 6, 7, 10, and 13 are shown in Figure 18.

The next obvious step is to consider the practical improvements achievable in the UHF system to reduce the 20 and 13.5 dB disparity gaps between UHF Channel 42 and VHF Channels 4 and 10.

In both instances the UHF Channel 42 was operating at an ERP of 650 kw which appears to be the power most commonly employed currently by non-commercial UHF stations. An increase in ERP to 5000 kw or 5 megawatts which is the maximum authorized will reduce the disparity in each case by about 9 dB.

This leaves a Δ C/N disparity of 11 dB with respect to VHF Channel 4 and 4.5 dB with respect to Channel 10.

The use of UHF receiving antennas of higher gain than those normally employed for VHF reception would reduce the disparity further.

In Section 4 it was pointed out that gain antennas of the type normally used outside the primary service area generally exhibit gains on the order of 6 dB at low-band VHF, 9 dB at high-band VHF, and about 12 dB for mid-band UHF. Thus, an additional antenna improvement of 6 dB with respect to Channel 4, and 3 dB with respect to Channel 10 is practical.

The reduction of receiving antenna transmission line losses as a means of reducing the disparity does not appear to be a fruitful approach since the 1.5 dB differential is already low for a 50-foot antenna downlead. Of course,

it is assumed that the transmission line is in good condition and properly installed - particularly if it is of the unshielded 300-ohm ribbon type.

So far, we have not tapped the possibility of achieving comparable system performance by the reduction of the average noise figure in the UHF tuners. How much improvement can be obtained without the use of low-noise RF stages through improved design and better quality control can only be guessed at at this time.

Reference to Figure 15 in Section 6 reveals that noise figures as low as 9 dB have been found in TV receivers with UHF tuners not provided with RF preamplifiers! Obviously, there is room for improvement in this area.

Concluding this section, it would appear that the most practical and economical approach to reducing the VHF-UHF system performance gap would be to improve each subsystem to the maximum degree practical so that the use of effective radiated powers of 5 megawatts, which are characterized by high capital and operating costs, could be avoided.

The following allocation of improvements in each subsystem is recommended as a practical means of achieving this goal:

| | Ch 4 Reference | Ch 10 Reference |
|---|---|---|
| ERP Increase (650 kw to 2 megawatts) | 5 dB | 5 dB |
| Receiving Antenna Gain increase | | |
| a) With respect to Ch 4 (6 dB to 16 dB) | 10 dB | |
| b) With respect to Ch 10 (9 dB to 16 dB) | | 7 dB |
| Noise Figure Decrease (13 dB to 10 dB) | 3 dB | 3 dB |
| Total | 18 dB | 15 dB |

Thus the 20 disparity with respect to Channel 4 could be reduced to a mere 2 dB, and the 13.5 dB gap with respect to Channel 10 could be closed with 1.5 dB to spare!

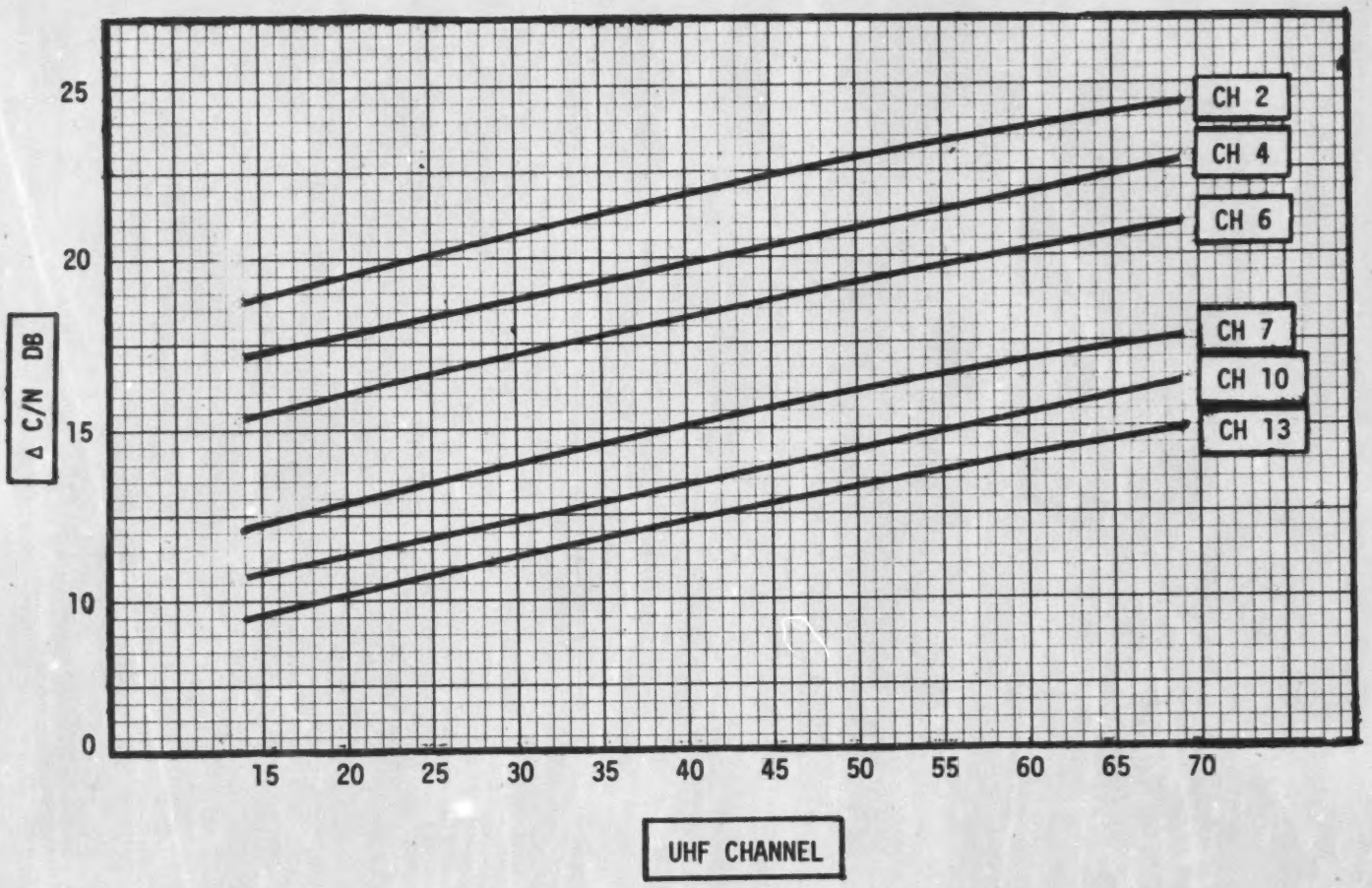


FIGURE 18: CARRIER TO NOISE RATIO DISPARITY BETWEEN ALL UHF CHANNELS RELATIVE TO SIX VHF CHANNELS

At this point at least two practical aspects of the VHF-UHF disparity problem should be recognized. They are:

a. The disparity that normally exists between the typical UHF system and the typical VHF system is not nearly as significant in strong signal areas within the city grade areas as it is near the limits of the grade B contours. As long as an adequate signal level is available to provide an essentially snow-free picture for the type of antennas used, such as a built-in loop, the availability of higher signal levels will contribute little to the picture quality which is already satisfactory. Accordingly, it is hardly necessary - or likely - that viewers will undertake the expense and trouble of installing a high-gain UHF receiving antenna. However, the situation is quite different in the weak signal areas where the VHF-UHF C/N ratio disparity produces an equal disparity in picture quality.

b. Although it has been demonstrated that the use of UHF antennas exhibiting gains of the order of 16 to 19 dB is a desirable means of closing the VHF-UHF disparity gap, UHF broadcasters will be facing a major challenge convincing a large majority of UHF viewers that they should purchase and install an adequate receiving antenna.

Nevertheless, the inescapable conclusion is that although UHF TV broadcasting frequently suffers a serious performance gap when compared to VHF, comparable performance with VHF, when terrain factors are not a problem, is not an illusory goal.

At this time, we can encouragingly remind ourselves that not too long ago engineers and broadcasters (as well as TV viewers) bemoaned the performance disparity of high-band VHF channels with respect to low-band VHF channels. As a result of increased understanding of the fundamental differences in subsystem performance, the gradual improvement in high-band VHF antennas, receiver performance, and the almost universal use of maximum authorized ERP of 316 kw, the disparity became insignificant or virtually disappeared. History can, and must, repeat itself.

## SECTION 8

## SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This report has treated the major elements of the transmission/reception system which influence the performance disparity between UHF and VHF within the constraints of the stated assumptions and has shown the extent to which various elements of the system may be improved, subject to certain technical and economic limitations.

Several conclusions may be drawn from the data contained in this report on the comparative performance of UHF and VHF systems. The more important of these conclusions can be summarized as follows:

1. For the foreseeable future, it does not appear to be economically feasible to utilize UHF effective radiated powers in excess of 5 megawatts as a means of overcoming deficiencies in other portions of the UHF transmission/reception system. However, for those non-commercial UHF stations which are now "under-powered", and experiencing coverage difficulties, an increase in ERP up to a level of nominally 2 megawatts, and an increase in antenna height above average terrain where necessary, is highly desirable.

2. Propagation loss due to the presence of obstructions, or obstacles which intercept the line-of-sight path to the receiving antenna, is always higher at UHF than at VHF and is the one element in the total system which is not subject to reduction.

3. UHF receiving antenna gain cannot be increased sufficiently to provide a "capture area" fully equivalent to that readily attainable with VHF antennas because of the problem of rapidly decreasing beamwidth with gain characteristic of UHF receiving antennas.

4. No significant improvement can be expected by using lower-loss line between the UHF receiving antenna and the receiver UHF tuner, provided existing transmission lines are in good condition, properly installed and not over 100 feet in length.

5. An improvement in system performance by reduction of the noise figures of UHF tuners is feasible and should be pursued.

Identification of a problem obviously does not directly result in a solution to that problem; however, such identification is an essential first step toward solution. It is important to emphasize that a systems approach to UHF problems is mandatory if meaningful progress is to be made. Emphasis on the improvement of one element will result either in an ineffectual solution or one which is

infeasible from a technical and/or economic standpoint. For example, as has been mentioned earlier, an attempt to equalize UHF-VHF performance by the single expedient of raising UHF effective radiated powers well above the regulatory 5 megawatt limit would be an exercise in futility in that regulatory approval would be unlikely and the economics unaffordable unless an efficiency/cost breakthrough develops.

This report would be incomplete without at least some general recommendations for improving the lot of the UHF broadcaster.

Just as improvements in any single subsystem discussed in this report will not be sufficient to reduce the total system performance disparity between UHF and VHF, neither will any single group likely succeed in bringing about the necessary changes. Several groups who must be involved in the solution to the UHF problem are listed in the introduction to this report. A functional division of these groups may be made into organizations which must serve as advocates of UHF improvement such as CPB, NAEB, PBS, ACTS, AMST, etc., and those groups whose cooperation is necessary to implement UHF improvements, such as the FCC, EIA, NESDA, etc. There would be a temptation to further classify these groups into those which would benefit from UHF improvement and those which would not benefit directly and would have to expend time, effort, and funds to assist in implementation of UHF improvement. However, this classification seems unnecessary since, in the final analysis, it will be the public which will benefit from UHF improvements, and all the groups mentioned profess a public service function.

It is important, and even crucial, to the goal of UHF improvement, that the groups cast in the role of advocates of UHF improvement have adequate and accurate information on the nature of the fundamental differences between UHF and VHF and an understanding of technical and economic feasibility of the recommended measures for improvement. Only in this way can these groups speak with a unified and reasoned voice in advocating the required improvements.

Following is a series of recommended activities to be undertaken to implement the steps necessary to approach parity of performance between UHF and VHF broadcasting/reception systems. Following the recommendations is a suggested division of tasks among the groups which can contribute to the desired goal.

1. Improvements in the Transmission System

The planning of new UHF facilities, and plans for the improvement of existing facilities must include budgets sufficient to provide an effective radiated power of the order of two megawatts and antenna heights above at least 1000 feet above average terrain.

It is one thing to champion the cause of high power UHF operation, and another to make viable suggestions for a source of funding. It would seem that a significant contribution to the funding problem would be to convince those responsible for the disbursement of federal matching funds, of the importance of high-power UHF operation in the two megawatt range in the hope that they would assign a high funding priority to applicants proposing to improve existing UHF transmission facilities and those proposing new high-power UHF facilities. As a corollary to this recommendation, Congressional appropriations committees must be made aware of the need for additional federal funding to provide Public Stations with transmission facilities comparable to their commercial counterparts.

Since high-power operation is essentially a matter of economics, the identification of additional, yet untapped sources of funding would seem appropriate. Pursuing some of the recommended funding sources such as the TV receiver tax advocated by the Carnegie Commission would appear worthwhile. Whatever the source of funding, the need for shifting the average ERP of Public UHF television facilities from the mode value of 650 kw to at least two megawatts is clear.

2. Improvements in the Noise Figure of UHF Tuners:

As long as receiver manufacturers continue to produce UHF tuners with sensitivity and selectivity characteristics considerably worse than those of VHF tuners, the de facto control of spectrum management, and at least partial responsibility for the disparity of UHF vs VHF performance rests with the receiver manufacturing industry and not with the Federal Communications Commission.

The existence of UHF tuners with noise figures on the order of 9 dB demonstrates that through the proper choice of components and adequate quality control, significant improvements can be made in the present type of UHF tuner which utilizes a crystal mixer without an RF pre-amplifier. However, it is believed that development of UHF tuners with an RF amplifier should be undertaken. The addition of the RF amplifier can provide not only a lower noise figure, but will also make possible elimination or reduction of the UHF "taboos" which presently exist in FCC UHF allocation standards. These "taboos" which require specified mileage spacings to be maintained between a given UHF channel and other UHF facilities removed by as many as 15 channels, are the result of an allocations policy designed to accommodate selectivity inadequacies in the tuner.

The addition of a tuned RF stage to UHF tuners will provide sufficient selectivity to permit the reduction or elimination of these taboos, and therefore an increase in the availability of UHF channels. While it is true that a shortage of UHF channels presently exists only in large population centers, allocations policy must be forward looking and anticipate growth. Therefore, because of the need for both lower noise figures now and additional UHF channels in the future, the requirement for more stringent UHF tuner performance characteristics in the FCC Rules is imperative. The performance characteristic standard that is most overdue for revision is the noise figure upper limit of 18 dB, presently permitted by Section 15.67 of the FCC Rules. This 18 dB noise figure standard is virtually an invitation to inadequate

quality control and cost cutting compromises in the manufacture of UHF tuners. The revision of FCC Rules relative to UHF tuners should start with a gradual "phased-in" lowering of the noise figure followed by the imposition of selectivity standards which will permit reduction or abolishment of the UHF taboos.

3. Dissemination of Information on Receiving Systems:

Most UHF station managers would be appalled to know the extent to which the quality of their signal as displayed on the screen of the typical home television receiver is completely outside the control of their carefully chosen technical staff. More likely, control rests with the judgment of the local TV serviceman who chooses and installs the viewer's receiving antenna system. In less favorable circumstances, control may reside with the so-called "expert" clerk in the local discount store who peddles to the "do-it-yourselfer" the so-called "super high-gain" UHF receiving antenna, "certified" to pull in stations 200 miles away, a roll of unshielded 300-ohm twinlead, a staple gun to attach the lead-in to the side of the house and a roll of friction tape to fasten the lead-in to the metal antenna mast! Experience has shown that there is a critical need to convey information on receiving antenna systems of the type contained in this report, to those service personnel responsible for the choice and installation of UHF receiving systems. In particular, the misconception that a "10 dB gain" antenna at UHF is equivalent in "signal-gathering" capability to a "10 dB gain" antenna at VHF must be overcome. The message on the engineering "facts of life" regarding UHF reception must be spread with evangelical zeal through every outlet available to the UHF broadcaster. On a local level, contact can be made with service personnel through local service organizations or through personal contact obtained by inviting service-men to partake of a buffet, a keg of beer, and a technical seminar on UHF reception at the station's studios.

On a national level contact can be made through such servicemen's organizations as the National Electronics Service Dealers Association (NESDA), and through articles written for trade publications. It would also be valuable to have questions relative to the technical aspects of UHF reception included in the licensing examinations of those states and cities which license and certify television servicemen, and on the "Certified Electronic Technician" examination administered by NESDA which provides nationwide accreditation of servicemen. That portion of the television viewing audience who are "do it yourself" types can also be reached through such outlets as the various "Popular" magazines (Popular Science, Popular Mechanics, etc.). Once a sufficient infusion of truth regarding UHF receiving systems is initiated, it can become self-perpetuating through "word of mouth" propagation.

4. Continued Efforts Towards Identification of UHF Problems

The factors associated with UHF transmission/reception systems are complex. This report has neither identified all of the problems nor given a completely exhaustive treatment to the problems which have been identified. Considerable additional research of both a theoretical and practical nature will be required before a clear and complete definition of the significant differences between VHF and UHF performance can be achieved. The laboratory for the additional practical research is the network of Public UHF stations. Consequently, we must collate the field experience of the Public UHF stations to discover the reasons underlying coverage problems as well as to discover why some Public stations encounter fewer coverage problems than other stations with equivalent transmission facilities and similar terrain conditions.

In delving further into the problem of UHF-VHF parity, it is important to recognize that the goal is one that may never be completely realized without significant expenditure of funds. The engineering facts point to the conclusion that, on the average, the VHF station will always have a performance advantage particularly covering an

area characterized by rough terrain and will be less costly to implement and operate than a UHF station of comparable performance. Notwithstanding the fact that significant improvements can, and should be made in the UHF system, it can be said with almost complete certainty, that the day will not arrive when a UHF broadcaster in an intermixed market would not gladly exchange his transmission facilities for similar facilities on a VHF channel.

This view may be unpopular, and could be construed by some to be an anti-UHF posture or an expression of defeat. Nonetheless, it is a conclusion soundly supported by the available facts. Differences in performance as a function of operating frequency are not unique to the UHF vs VHF situation. Stations at the low end of the AM Radio Broadcast Band have greater coverage than stations at the upper end, and, in general, low-band VHF television stations have fewer coverage problems than do VHF high-band stations.

If efforts to narrow the performance gap between VHF and UHF succeed to the degree that the viewing public is unaware of performance differences, a significant victory will have been won.

Distribution of Effort

If the goal of UHF improvement is to be achieved, an equitable division of tasks among the various groups with an interest in UHF improvement must be made.

The interests, purposes, and expertise of the various groups involved suggests a logical distribution of responsibilities among them. Suggestions for distribution of these areas of responsibility are contained in the following listing. The divisions represent an opinion on what may be the most appropriate and efficient activities for given groups, and should not be construed as an attempt to assign tasks nor to limit the activities of any given group.

| TASK | PARTICIPATING ORGANIZATIONS |
|---|---|
| ADDITIONAL RESEARCH INTO THE COMPARISON OF VHF-UHF SYSTEMS AND UHF PERFORMANCE IMPROVEMENTS: | Engineering staffs of the Public Television stations coordinated through the PBS Engineering Committee and the Office of Engineering Research of the Corporation for Public Broadcasting.<br><br>Society of Broadcast Engineers.<br><br>Engineering staffs of the commercial UHF stations coordinated through the All-Channel Television Society.<br><br>Joint Council on Educational Telecommunications.<br><br>Department of Commerce, National Bureau of Standards.<br><br>Association of Maximum Service Telecasters.<br><br>Engineering Department of the National Association of Broadcasters.<br><br>Broadcast Group of the Institute of Electrical and Electronic Engineers. |
| INVESTIGATION INTO THE MEANS OF PROVIDING INCREASED SENSITIVITY AND SELECTIVITY OF UHF TUNERS: | Engineering staffs of receiver and tuner manufacturers through the Consumer Electronics, Division of the Electronics Industries Association.<br><br>Engineering staffs of semiconductor manufacturers coordinated through the Consumer Electronics Division of the Electronics Industries Association.<br><br>FCC Laboratories.<br><br>CPB Office of Engineering Research. |
| RESEARCH INTO MORE EFFICIENT UHF ALLOCATIONS THROUGH ELIMINATION OF THE UHF TABOOS: | Federal Communications Commission.<br><br>Joint Council on Educational Telecommunications.<br><br>Association of Maximum Service Telecasters.<br><br>Engineering Department of the National Association of Broadcasters. |

| | |
|---|---|
| | Office of Telecommunications Policy. |
| | CPB Office of Engineering Research. |
| | National Association of Educational Broadcasters. |
| | National Association of Broadcasters. |
| PLANS FOR THE DISSEMINATION OF INFORMATION ON UHF PRINCIPLES AND UHF ANTENNA CHOICE AND INSTALLATION TECHNIQUES: | National Electronic Service Dealers Association. |
| | Engineering staffs of the Public Stations coordinated through the PBS Engineering Committee. |
| | Engineering staffs of the Commercial UHF stations coordinated through the All-Channel Television Society. |
| | Office of Engineering Research of the Corporation for Public Broadcasting. |
| | Engineering staff of antenna/transmission line manufacturers coordinated through the Consumer Electronics Division of the Electronics Industries Association. |

Optimally, the above organizations could operate under the overall supervision of an ad-hoc UHF Improvement Committee similar to the Television Allocations Study Organization which coordinated the activities of 139 separate organizations concerned with UHF-VHF allocations problems in the late fifties.

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# APPENDIX

## DEMONSTRATION OF THE EQUIVALENCE OF METHOD A AND METHOD B FOR CALCULATING THE RECEIVING ANTENNA OUTPUT SIGNAL VOLTAGE

The equivalence of Method A and Method B described in Section 3 as alternate procedures for calculating the signal voltage available at the receiving antenna output terminals can be readily demonstrated. The procedures outlined in Method A and Method B on page 15, Section 3, can be summarized symbolically as follows:

METHOD A:

$$V_0 = \sqrt{Z_A P_A} = \sqrt{Z_A \left[\text{Antilog } \left(\frac{ERP + 2.2 - \beta - \alpha}{10}\right)\right]}$$

Where $\alpha_1 = 36.6 + 20 \log D + 20 \log F$

METHOD B:

$$V_0 = \left[\frac{300}{2\pi F}\right]\varepsilon = \left[\frac{47.77}{F}\right] \sqrt{Z_0 \left[\text{Antilog } \left(\frac{ERP - \beta - \alpha}{10}\right)\right]}$$

Where $\alpha_2 = 75 + 20 \log D$

Where:

$V_0$ is the antenna output in volts,
$Z_A$ is the antenna impedance (75 ohms),
$P_A$ is the received power in the antenna,
ERP is the transmitter Effective Radiated Power,
D is the distance between transmitter and receiver in statute miles,
F is the frequency in Megahertz,
$\varepsilon$ is the field strength in volts per meter,
$Z_0$ is the characteristic impedance of free space (377 ohms),
$\alpha_1$ is the free space path loss in decibels for Method A,
$\alpha_2$ is the free space loss for Method B, and
$\beta$ is the total obstruction loss in decibels, which in combination with the appropriate $\alpha$, constitutes the total path loss in both methods.

The following system parameters are selected for the demonstration:

| | |
|---|---|
| Frequency (Ch 11) | 200 mHz |
| ERP (100 KW) | 20 dBk or 50 dBw |
| Distance | 10 SM |
| Receiving Antenna | $\lambda/2\pi$ dipole* |
| Obstruction loss ( $\beta$ ) | 20 dB. |

The impedance of $Z_A$ of the half-wave dipole is 75 ohms and the characteristic impedance $Z_0$ of free-space is 377 ohms.

Substituting in equation (1) under Method A:

$$V_0 = \sqrt{75\ [\text{Antilog}\ (\frac{50 + 2.2 - 20 - \alpha}{10})]}$$

Since for method A:

$$\alpha = 36.6 + 20\ \log D + 20\ \log F = 36.6 + 20 + 46.02 = 102.62\ \text{db}$$

$$V_0 = \sqrt{75\ [\text{Antilog}\ (-7.042)]} = \sqrt{75/\text{Antilog}\ 7.042}$$

$$= 75 \times 9.1 \times 10^{-8} = 2.6\ \text{Millivolts}$$

---

* The output signal level for an antenna of known gain with reference to a half-wave dipole can be readily established from the known output of the reference half-wave antenna.

Substituting the same system parameters in equation (2) under Method B:

$$V_0 = \left[\frac{47.77}{200}\right] \sqrt{377 \left[\text{Antilog } \left(\frac{50 - 20 - \alpha}{10}\right)\right]}$$

For Method B:

$$\alpha = 75 + 20 \log D = 75 + 20 = 95 \text{ db}$$

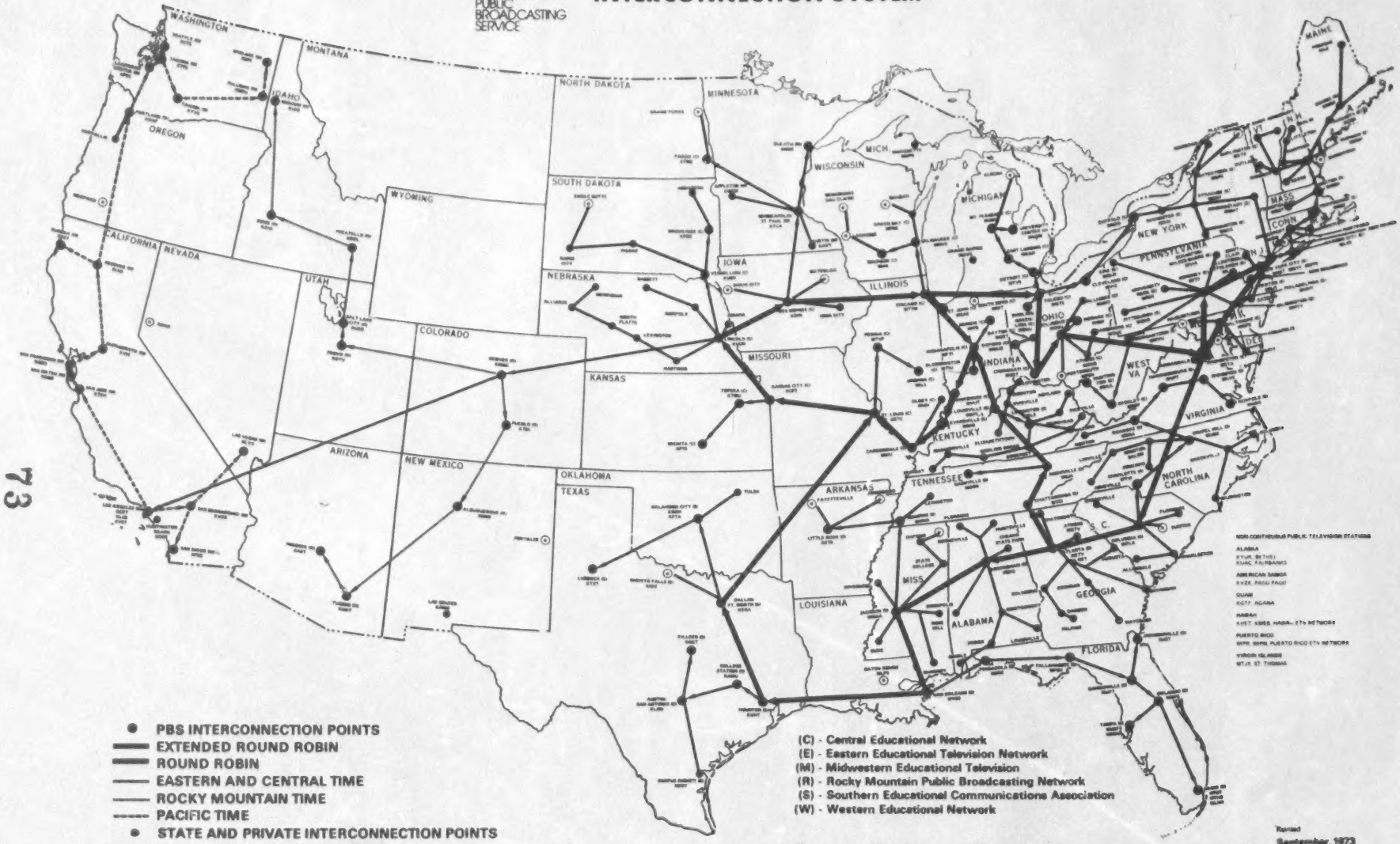
$$V_0 = 0.239 \sqrt{377 \left[\text{Antilog } (-6.5)\right]} = 0.239 \sqrt{377/\text{Antilog } 6.5}$$

$$= 0.239 \quad 377 \times 0.316 \times 10^{-6} = 2.6 \text{ Millivolts}$$

Thus, the calculated antenna output signal voltage by Method B checks with that obtained by Method A, although it is Method B which is descriptive of the behavior of the Propagation Path-Receiving Antenna System.

PBS
PUBLIC BROADCASTING SERVICE

# INTERCONNECTION SYSTEM




- PBS INTERCONNECTION POINTS
- EXTENDED ROUND ROBIN
- ROUND ROBIN
- EASTERN AND CENTRAL TIME
- ROCKY MOUNTAIN TIME
- PACIFIC TIME
- STATE AND PRIVATE INTERCONNECTION POINTS
- STATE AND PRIVATE NETWORK
- NON-INTERCONNECTED STATIONS ON AIR
- PROJECTED ACTIVATIONS THROUGH DECEMBER, 1974

(C) - Central Educational Network
(E) - Eastern Educational Television Network
(M) - Midwestern Educational Television
(R) - Rocky Mountain Public Broadcasting Network
(S) - Southern Educational Communications Association
(W) - Western Educational Network

The Designation In ( ) Indicates The Transmission Received During Regional Transmission Hours.
No Affiliation Is Necessarily Implied.
This Map Is Based On AT & T Pricing, And Does Not Necessarily Indicate Actual Routing.

Revised
September, 1973
AL MDL DW
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